LAKESHORE CAPACITY STUDY

COMMITTEE REPORT

JULY 1986

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Ontario
Ministry of Municipal Affairs
Bernard C. Grandmaitre, Minister

Research and Special Projects Branch

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Fisheries
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Trophic Status
Wildlife
Integration

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LAKESHORE CAPACITY STUDY

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LAKESHORE CAPACITY STUDY

Muskoka-Haliburton Area

0 5 10 15 20 25 30 35

Scale in kilometres

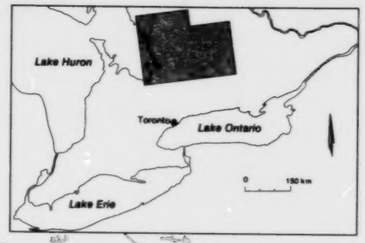
COMPONENTS:

- Wildlife
- Trophic Status
- All
- Microbiology
- Fisheries
- Land Use

The regional survey by the Land Use Component of cottages on portions of lakes is not included

Note: Circle sizes for Cartographic purposes only

Cartography by Ministry of Municipal Affairs and Housing, 1981



Eagle Lake
Bernard Lake
Pickerel Lake
Island Lake
Grass Lake
Jacks Lake
Loon Lake
Sand Lake
Three Mile Lake
Groom Lake
Peters Lake
Clam Lake
Doe Lake
Clear Lake
Emsdale Lake
Foote Lake
Bella Lake
Walker Lake
Perch Lake
Oudaze Lake
Rebecca Lake
Jerry Lake
Harp Lake
Dotty Lake
Oxbow Lake
Little Clear Lake
Buck Lake
Solitaire Lake
Seventeen Mile Lake
Troutspawn Lake
Lower Fletcher Lake
McFadden Lake
Clinto Lake
Bear Lake
Tock Lake
Kawagama Lake
Johnson Lake
Macdonald Lake
North Lake
Redstone Lake
Percy Lake
Haliburton Lake
Kennisis Lake
Eagle Lake
Moose Lake
Mouse Lake
Plastic Lake
Big Hawk Lake
Little Hawk Lake
Maple Lake
Kabakwa Lake
Halls Lake
Pine Lake
Glen Lake
Bass Haunt Lake
Drag Lake
Green Lake
Hurricane Lake
Twelve Mile Lake
Head Lake
Two Islands Lake
Miskwabi Lake
Esson Lake
Long Lake
Mountain Lake
Kashagawigamog Lake
Glamour Lake
Billings Lake
Silent Lake
Lake St. Peter
Bancroft
Minden
Gull River
Irondale River
Gull Lake
Little Bob Lake
Sludge Lake
Davis Lake
Mississagua Lake
Lower Buckhorn Lake
Lovesick Lake
Paint Lake
Shoe Lake
Mink Lake
Chub Lake
Grandview Lake
Martin Lake
Blue Chalk Lake
Black Lake
Red Chalk Lake
Cinder Lake
Brady Lake
Kushog Lake
Boshkung Lake
Head Lake
Four Mile Lake
Dairymple Lake
Peninsula Lake
Fairy Lake
Lake of Bays
Huntsville
Lake Vernon
Skeleton Lake
Mary Lake
Beattie Lake
Clearwater Lake
Menominee Lake
Fawn Lake
Bonnie Lake
Big Stephen Lake
Moot Lake
Sage Lake
Echo Lake
Dickie Lake
Wildcat Lake
Rii Lake
Guilleather Lake
Croseon Lake
Pine Lake
Gilleach Lake
Healey Lake
McKay Lake
Leach Lake
Wood Lake
Clear Lake
Bigwind Lake
Bird Lake
Stewart Lake
Joseph Lake
Rosseau Lake
Leonard Lake
Bracebridge
Muskoka
Muskoka Bay
Gravenhurst
Three Mile Lake
Kahshe Lake
Severn River
Black River
Lake Couchiching
Orillia
Lake Simcoe
Georgian Bay
Parry Sound
Lake Vernon
Skeleton Lake
Mary Lake
Beattie Lake
Clearwater Lake
Menominee Lake
Fawn Lake
Bonnie Lake
Big Stephen Lake
Moot Lake
Sage Lake
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Muskoka Bay
Gravenhurst
Three Mile Lake
Kahshe Lake
Severn River
Black River
Lake Couchiching
Orillia
Lake Simcoe
Georgian Bay
Parry Sound

THE DISTRICT OF PARRY SOUND
THE DISTRICT MUNICIPALITY OF MUSKOKA
THE COUNTY OF SIMCOE
THE COUNTY OF VICTORIA
THE DISTRICT OF NIPISSING
PROVISIONAL COUNTY OF HALIBURTON
THE COUNTY OF HASTINGS
THE PROVISIONAL COUNTY OF HALIBURTON
THE COUNTY OF PETERBOROUGH

FOREWORD

Community planners and other professionals involved in the preparation of planning policies for lakeshore development and in the review of specific subdivision proposals have always found it difficult to determine objectively the impact of development on the natural environment. In response to this challenge, the Lakeshore Capacity Study was undertaken to provide a planning tool to assist in evaluating the effects of cottage development on inland lakes and lakeshores. Central to the task was the need to gain a clearer understanding of the relationship between cottage development and its impacts on selected aspects of the natural environment.

To accomplish these objectives, the Ministry of Municipal Affairs carried out the Lakeshore Capacity Study in cooperation with the Ministry of the Environment and the Ministry of Natural Resources.

The Muskoka-Haliburton area of central Ontario was chosen as the Study Area. The homogeneity of the area, which is part of one physiographic region, reduced the need to account for major natural variations among the lakes and watersheds. In addition, the extent of existing development on the lakes varied, permitting an examination of situations ranging from no development to full development.

The Study involved measuring the source of environmental impact, in terms of the lakeshore cottages and their use, and the impact of cottage development in terms of water quality, fisheries, and wildlife habitat. The methods of prediction derived from the research were linked in a simulation model, which is capable of predicting trends in the values of the key indicators of impact.

As the research, analysis and findings of the Study are documented in a set of seven reports, selective reading may be desirable. Those readers who have a general interest in the work are advised to read this Committee Report first, as it provides an overall summary of the findings. This should be followed by the Integration report, in which the simulation model is described. Readers with more specialized interests will find the details of each component of the Study in the other five reports. In each, the reader can select from the table of contents the most important chapters for his or her purposes.

The end product of the Study, the Ontario Lakeshore Capacity Simulation Model, has several features worth noting. The spatial unit addressed by the model is a single lake and the lakeshore. When the model is applied, the number of unknowns related to the natural environment can be substantially reduced, making it easier for planners or other professionals to weigh the environmental effects of development. The model goes a step further to permit predictions of the impact of cottage development when different management policies are selected.

The scope of the simulation model demands some explanation. In its present form, the model applies to cottage development on inland lakes in the Study Area, where the research was conducted. However, the methods of prediction

can be adapted to other parts of the province, as long as differences in conditions are taken into account.

The purpose of the Study was to measure the environmental impact of cottages. Commercial and industrial uses were excluded deliberately, in order to simplify the difficult task of measuring cottage impact. The flexibility inherent in the simulation model makes it possible to add other types of land use later, if so desired.

Most of the existing cottage development in the Study Area is located in a single tier along the shoreline. For this reason, the simulation model applies to the immediate lakeshore and not to backshore development. Again, the methods of prediction developed for cottages near the lake can be adapted to measure the impact of cottage development in other forms.

The model was designed to measure the physical and chemical impacts of cottages. Accordingly, it does not address other planning concerns, such as social and economic impacts. While these were recognized as essential considerations in decision-making, the specific objective of Phase III of the Lakeshore Capacity Study was to find practical ways of producing better technical data regarding environmental impact.

Now that Phase III of the Study is completed, with the production of the Ontario Lakeshore Capacity Simulation Model (OLCSM), the next step envisaged is to apply the model experimentally within the Ministry. In this setting, model output can be tested in a variety of actual development situations. When this period of experimental use has been concluded and the results assessed, the three participating ministries will be able to determine whether the model should be adapted to other parts of the province and whether it should be made available more widely.

The Ministry of Municipal Affairs considers the OLCSM to be a potential planning tool but recognizes that the technical and organizational implications of its use must be examined. While this is underway, the model will be available for testing as an additional planning tool to supplement the information normally required to evaluate a planning policy or development proposal. However, the model will not be used in the decision-making process, which will still rest on the customary range of planning considerations.

This Committee Report describes the Lakeshore Capacity Study results in terms of their underlying principles and practical applications.

ACKNOWLEDGEMENTS

The material in this report is drawn largely from reports prepared by the managers and senior staff of individual components of the Lakeshore Capacity Study. A conscious effort has been made, within the bounds of a general summary, to convey the essence of their original work.

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PREFACE

This report is addressed to planners and others who are interested in a general overview of the Lakeshore Capacity Study. The focus is on results, with sufficient background provided to make them comprehensible. Models developed by the research teams to predict cottage use and the impact of lakeshore development on the land-lake system are described in terms of their underlying principles and practical capabilities.

A more detailed account of the Ontario Lakeshore Capacity Simulation Model (OLCSM) appears in the Integration report. It describes the submodels and their linkages more fully and includes all the equations.

Those interested in the research design and methods will find a record of the supporting research and results in the other Lakeshore Capacity Study reports: Land Use, Trophic Status, Microbiology, Fisheries and Wildlife. These reports document the data collection procedures, analytical methods, research results and modelling processes, together with the mathematical formulations of functional relationships in the models.

The Summary at the beginning of this Committee Report presents the results of the Lakeshore Capacity Study in terms of their relevance to lakeshore planning and development.

Chapter 1 outlines the objective and scope of the Lakeshore Capacity Study and its management structure. Part A describes the Ontario Lakeshore Capacity Simulation Model (OLCSM) and its potential as a practical planning tool. Part B reviews the research results and the methods which were developed to predict lakeshore cottage use and the impact of lakeshore development on water quality, public health, fisheries and wildlife.

SUMMARY

This Summary presents the results of the Lakeshore Capacity Study in terms of their relevance to lakeshore planning and development. The material is arranged in the same sequence as the report.

INTEGRATION COMPONENT

The Integration Component team constructed a state-of-the-art simulation model to predict the effects of lakeshore cottage development on water quality, fisheries and wildlife, for inland lakes in the Study Area. The adaptive environmental assessment and management (AEAM) approach inherent in the Ontario Lakeshore Capacity Simulation Model (OLCSM) is specifically designed to assist in ecological decision-making in real-world situations.

The OLCSM is technically sound, based as it is on relationships and methods derived from the Lakeshore Capacity Study research. The innovative work of the research component groups, with supplementary knowledge from the scientific literature, is the most advanced in the field.

While the Lakeshore Capacity Study research involved complicated concepts and analyses, the end product of the Study is a relatively simple, practical planning tool. The Ontario Lakeshore Capacity Simulation Model responds to simple commands, operates with readily available data and generates the predictions quickly.

The OLCSM offers several advantages over four separate models. First, explicit linkages between the submodels simulate ecological interactions more realistically, as natural processes operate without regard to the areas of responsibility of specific ministries. For example, water and fish are inseparable ecologically, even though they may be separated for administrative purposes. Second, input data for a particular lake is entered into the computer only once, thus ensuring consistency in the data base for all the predictions. Third, the OLCSM predicts over time the values of indicators that measure the state of the environment. As the values are calculated for each annual time-step, the user will know when any undue stress on the environment is likely to begin and can act accordingly. Fourth, the OLCSM can simulate the effects of different management strategies designed to mitigate the impact of development on the environment.

LAND USE COMPONENT

The models developed by the Land Use Component planners and social scientists, as part of the Lakeshore Capacity Study, are capable of predicting cottage use, for a specific lake, with greater precision than was previously possible. The Accessibility and Cottager models are sensitive to variations in cottage use between lakes and between cottages. Accordingly, more realistic estimates can be obtained by using the models than by assuming maximum use of each cottage.

The value of realistic cottage use predictions is evident in the context of the simulation model. When the predictive methods developed by the individual components are incorporated into the Ontario Lakeshore Capacity Simulation Model, the prediction of cottage use becomes the driving variable. In the Water Quality submodel, for example, estimates of anthropogenic phosphorus input to the lake from septic systems are derived, in part, from the predicted annual user-days. Thus, good predictions of cottage use tend to improve the predictions of environmental impact.

Quite apart from the Ontario Lakeshore Capacity Simulation Model, the Land Use Component models can be used independently to identify lakes where the pressure for cottage conversion is likely to be relatively high. Such technical information could assist planners who are responsible for drafting appropriate official plan policies and zoning regulations with respect to seasonal versus permanent residential uses on specific lakes.

TROPHIC STATUS COMPONENT

Models developed or refined by the Trophic Status Component scientists, as part of the Lakeshore Capacity Study, are capable of predicting the impact of lakeshore cottage development on the trophic status of lakes in the Study Area with greater accuracy than the models available previously.

In predicting the trophic status of a lake, the effects of upstream lakeshore development must be considered, as inflowing streams are one of the sources of phosphorus. The trophic status models can be used for each lake upstream, starting with the headwater lake, in order to calculate the phosphorus load in streams flowing into the lake where new development is proposed.

The Ministry of the Environment is responsible for surface water quality management. For several years, as part of the Ministry's water management program, the existing trophic status models have been used to assist in evaluating the effects of lakeshore development. The new Trophic Status Component models, based on the best scientific knowledge available, offer a more refined tool.

MICROBIOLOGY COMPONENT

Scientists in the Microbiology Component developed, as part of the Lakeshore Capacity Study, a better understanding of the relationships between high densities of swimmers, water quality and the risk of ear infection. When this was combined with the Land Use Component findings regarding cottage use and swimming activity, it was evident that extensive cottage development on the lakeshore could generate a higher risk of ear infection among swimmers.

The water quality criterion recommended by the researchers provides a specific benchmark for evaluating the risk of ear infection. The Ministry of the Environment is now using *Pseudomonas aeruginosa* as an indicator of the health of recreational waters, so their responses to the Ministry of Municipal Affairs regarding a proposed subdivision reflect this criterion.

The biologists' recommendations for beach location provide practical guidelines for minimizing waterborne concentrations of the pathogen *Pseudomonas aeruginosa*. The application of such guidelines could reduce the risk of swimmers contracting the ear infection *otitis externa*.

Finally, the recommendation to design beaches to encourage low densities of swimmers leads planners towards health-conscious site planning on the shores of inland lakes. Given the knowledge that high human loading of a beach can increase the risk of ear infection for swimmers, the lakeshore can be planned and developed to minimize risks. If the proposed cottage development is likely to generate a large number of swimmers or if the beach is also to be used by non-cottage swimmers, more than one beach may be appropriate. Alternatively, access to a large beach may be designed to distribute the swimmers more evenly along the shoreline. A method of calculating swimmer density and relating it to the risk of ear infection is included in the Ontario Lakeshore Capacity Simulation Model.

FISHERIES COMPONENT

The net productivity model developed by the Fisheries Component biologists, as part of the Lakeshore Capacity Study, is designed to estimate the fish catch, or fish yield, for a specific lake. When the predicted yield is compared with the estimated maximum sustained yield, fisheries biologists are able to judge whether the fishery is likely to be overexploited.

The net productivity model can be used to predict the yield not only for the fish community but also for one species. This is accomplished by using the estimated MSY (maximum sustained yield) value for the species in question, for example, lake trout. This model capability can assist fisheries biologists in evaluating the impact of lakeshore cottages on lake trout lakes.

The Ministry of Natural Resources is responsible for the management of commercial and sport fisheries in Ontario. As part of their fisheries management program, the ministry has used the fish yield estimated from the existing morphoedaphic index model as one of the criteria for setting catch quotas for some of Ontario's fisheries. The net productivity model, developed as part of the Lakeshore Capacity Study, offers a more refined tool for predicting fish catch for lakes with existing or proposed lakeshore cottage development.

WILDLIFE COMPONENT

Biologists in the Wildlife Component developed, as part of the Lakeshore Capacity Study, quantitative methods for predicting the impact on wildlife communities of residential development on the shores of inland lakes in the Study Area. Their innovative research provides new knowledge with respect to wildlife habitat needs.

The challenge for planners is to recognize the opportunities for coexistence of cottages and wildlife. Fortunately, some of the land requirements for wildlife habitat differ from those for cottages. Streams and wetlands, for example, provide ideal habitat for several wildlife species but poor sites for cottages.

The Ministry of Natural Resources has a specific mandate under the Endangered Species Act to protect endangered, rare and threatened species of wildlife. While none of these occur in the Study Area, studies of the red-shouldered hawk suggest that its nesting habitat is being reduced and that the population is declining.

The deer population is also a concern of the Ministry of Natural Resources. From a land use standpoint, this involves preserving deer concentration areas which are important to winter survival. Regional staff of the Ministry of Natural

Resources can provide information regarding the locations of deer yards, so these can be taken into account in planning for cottage development.

The wildlife recommendations provide guidelines for those who wish to improve lakeshore planning and development. By taking the needs of the wildlife community into account at the planning stage, developers may be able to enhance the potential of their cottage lots and thereby enlarge their share of the market.

The results of the Wildlife Component research can also benefit cottagers. With greater knowledge of the types of habitat needed by various wildlife species, cottagers will be able to avoid destructive action. Those who value the wildlife near their cottages may limit the removal of vegetation on their lots. Others may make a conscious effort to avoid disturbing nesting sites. While the actions of one cottage household are relatively small in scale, the cumulative effects could be considerable.

In short, the wildlife research results offer a wide range of pertinent knowledge which concerns cottagers and developers as well as biologists and planners.

1. INTRODUCTION

1.1 PROBLEM

For many years, community planners in Ontario have had difficulty evaluating subdivision proposals for cottage development on the shores of inland lakes. The problem stemmed from the absence of technical methods with which to determine objectively the impact of cottage development on the lake and surrounding land.

Similar problems were encountered in determining what policies should be included in regional and local official plans. Even more specific aspects of lakeshore planning, such as zoning standards and site planning, were hampered by the lack of relevant technical knowledge.

Without a recognized method of predicting impact, conflicting claims regarding the ecological repercussions of lakeshore cottages tend to generate confrontation. While development proponents may minimize the adverse effects, cottage owners often foresee dire consequences. Any reconciliation of such extreme positions is unlikely, as long as crucial gaps remain in scientific knowledge of the ecological relationships inherent in lake-watershed systems.

With a method of predicting impact prior to actual development, damage to the environment could be prevented by limiting the number of cottages to the carrying capacity of the lake. Such an approach would be more economical over the long term, as it would avoid the need for costly remedial action in the future.

1.2 OBJECTIVE

The objective of the Lakeshore Capacity Study Phase III was to develop a systematic method of predicting the impact of lakeshore cottages on selected aspects of the inland lake environment. It was clear from the initial work in Phases I and II that an in-depth examination of certain specific lake features, such as water quality and fisheries, could be expected to produce practical results. Further, the land elements of the land-lake system could be taken into account through wildlife-habitat investigations. Related to each of these was the need to find more effective ways of quantifying cottage development on the lakeshore, to enable identification of consistent relationships between cottages and water quality, fisheries and wildlife.

A practical necessity was that the methods, or models, must be able to produce projections without delay, so they could be used to expedite planning processes. To accomplish this, the input data would need to be assembled quickly. Thus, the variables and parameters selected as predictors would have to be restricted to those for which values would be readily available.

In view of the limits on current scientific understanding of lake-watershed systems, the model to be developed in Phase III was not viewed as the ultimate solution. Rather, a more realistic expectation was that it would be sound enough to merit practical application and flexible enough to allow future refinement.

Finally, it was clear that no model could solve all lakeshore planning problems. Nevertheless, by measuring the probable impacts of cottage development, the model projections could substantially reduce the number of unknowns with respect to environmental impact, making it easier for a planner to weigh the environmental factors along with other considerations. In this way, the model would be able to assist in lakeshore planning at the provincial, regional and local levels.

1.3 SCOPE

The Study Area selected was the Muskoka-Haliburton area of central Ontario. As this area is within one physiographic region on the Precambrian Shield, the soils and plant communities are similar throughout the area, thus reducing the need to account for major natural variations among the lakes and watersheds. With respect to cottages, the extent of existing lakeshore development varies, permitting examination of situations ranging from no development to full development.

The research was concerned with the physical and chemical impact of lakeshore cottages on the land-lake system, leaving other types of impact and land use to be investigated at some future time.

1.4 MANAGEMENT STRUCTURE

The Lakeshore Capacity Study research work was carried out within three ministries: Municipal Affairs and Housing, the Environment, and Natural Resources.

STEERING COMMITTEE

The Study was initiated, funded and managed by the Ministry of Municipal Affairs and Housing. In Phase III, a Steering Committee was established, with representatives from the participating ministries. The role of the Committee was to ensure that the study objectives were clearly understood, the approved research program was followed and the resources were properly allocated.

Table 1. Research management

Ministry	Component	Manager
Municipal Affairs and Housing	Integration	Géza C. Teleki*
	Land Use	Jean C. Downing
Environment	Trophic Status	P.J. Dillon
	Microbiology	C.A. Burger
Natural Resources	Fisheries:	
	Net Productivity	A.M. McCombie
	Littoral Zone	J.M. Harker**
	Wildlife	D.L. Euler

* Now with DeLeuw Cather, Canada Ltd. (DeLCan)
** Now with M.M. Dillon Ltd.

RESEARCH COMPONENTS

The research was carried out within several components in the three ministries. Managers of the various components were senior staff with knowledge and experience in research and in appropriate disciplines, including limnology, biology, microbiology and planning. The research management structure is set out in Table 1.

PEER REVIEW PROCESS

The Steering Committee introduced a peer review process to ensure that the Lakeshore Capacity Study research was technically valid, current and complete (Figure 1). Eminent scientists and planners from the private sector and from public agencies outside the Ontario public service were invited to act as peer reviewers (Appendix A). They examined the research design, methods and reports of individual components and provided constructive comments. This peer review process proved to be a valuable adjunct to the work of the research teams.

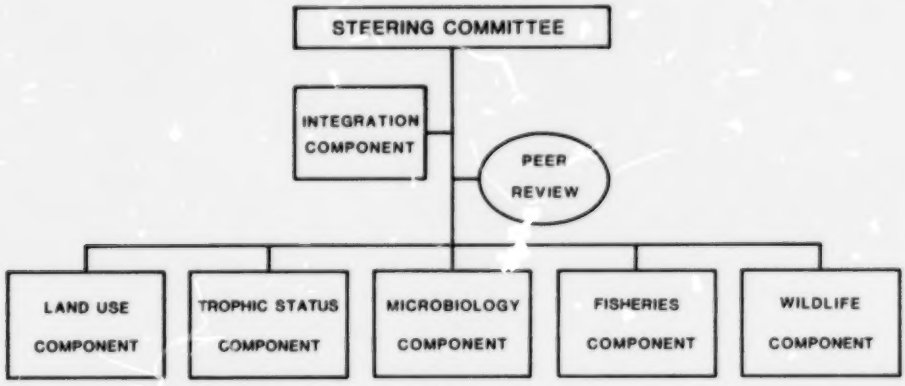

Figure 1. Lakeshore Capacity Study management structure

1.5 ACCOMPLISHMENTS

In each component, the research proceeded independently, within the framework of the Lakeshore Capacity Study as a whole. In some components, such as Trophic Status and Fisheries, the scientists were able to build on existing models; in others, such as Wildlife and Land Use, the researchers had to do pioneering work. Despite substantial differences in the nature of the research and the results, each component produced original, technically sound results, with practical implications for lakeshore planning.

Methods of predicting cottage use and the impact of lakeshore cottages on water quality, fisheries and wildlife were developed and incorporated into the Ontario Lakeshore Capacity Simulation Model (OLCSM), which is also capable of testing the effects of different management strategies designed to mitigate environmental impact. Thus, the objective of the Lakeshore Capacity Study Phase III has been achieved.

PART A. ONTARIO LAKESHORE CAPACITY SIMULATION MODEL

2. INTEGRATION COMPONENT

3. POTENTIAL APPLICATION OF THE ONTARIO LAKESHORE CAPACITY SIMULATION MODEL

2. INTEGRATION COMPONENT

The goal of the Integration Component was to combine the methods of prediction developed by the other Lakeshore Capacity Study components into a single predictive tool which would be capable of quantifying the effects of lakeshore cottage development on water quality, fisheries and wildlife.*

From a technical standpoint, the integrated model had to be able to produce sound information regarding selected indicators of the environment. Further, it must be flexible enough to allow revision and improvement based on new scientific knowledge and experience.

From a practical standpoint, the model had to be reasonably simple for users to apply. In addition, it must be able to generate predictions quickly and present them clearly.

2.1 EXISTING MODEL

An adaptive approach to environmental impact assessment and management was developed in the 1970's at the Institute of Resource Ecology, University of British Columbia. The approach is described in a book edited by C.S. Holling and published by the International Institute for Applied Systems Analysis (Holling, 1978).

The Adaptive Environmental Assessment and Management (AEAM) approach involves the construction of a dynamic, computerized, simulation model which explicitly accounts for interactions between compartments of the system under study.

The inner workings of the simulation model are mathematical relationships, based on current understanding of lake-watershed ecosystems. The model output, in the form of projections of values for selected environmental indicators, provides information on the development capacity of the lake under consideration.

A key feature of the AEAM model is its ability to simulate the environmental consequences of different management strategies. Tangible measures of environmental impact make it possible to evaluate the options. With this type of analysis, a lake may have several acceptable levels of cottage development, depending on the specific management policy selected.

2.2 APPROACH TO DEVELOPING THE SIMULATION MODEL

The Integration Component scientists used the AEAM approach in constructing the Ontario Lakeshore Capacity Simulation Model. The method involves a co-ordinated, interdisciplinary approach that takes into account the needs and concerns of the ultimate users. Inherent in the process are short, intensive, modelling workshops which, for the Lakeshore Capacity Study, included scientists, planners, resource managers and policy advisors from the three participating ministries.

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* This chapter is based on the report Lakeshore Capacity Study, Integration (Teleki and Herskowitz, 1986).

Consultants from Environmental and Social Systems Analysts Ltd. (ESSA) were engaged to give clear direction to the modelling process. They acted as facilitators at the workshops and also designed and coded the initial Ontario Lakeshore Capacity Simulation Model (OLCSM).

Integration Component representatives also held a series of technical meetings with component managers and their senior staff, to resolve technical problems and to ensure consensus regarding the concepts and relationships expressed in the OLCSM equations.

2.3 ONTARIO LAKESHORE CAPACITY SIMULATION MODEL

The Ontario Lakeshore Capacity Simulation Model (OLCSM) is a type of simulation model sometimes referred to as a "state-transition discrete-time" model, because the state of the system is described by variables that are changed at specified intervals of time. All natural events, such as precipitation, lake discharge and growth of the fish population, are implemented from the start of the simulation. Random variation is applied to the annual nutrient loadings from precipitation and drainage, within the range observed in field studies.

Existing cottages are "built" at the start of the simulation. At any time thereafter, in response to a user-specified construction rate, cottages are built along the lakeshore on existing vacant lots and on lots in the proposed subdivision.

The inner workings of the model that provide the system dynamics (rules for change) describe in mathematical terms those processes and linkages between variables that are necessary for the prediction of environmental impact (Figure 2). These rules are primarily a product of functional relationships derived from the Lakeshore Capacity Study research, with supplementary data from the scientific literature and, where necessary, intuitive understanding of the lake-watershed system by experienced scientists. The levers represent the management strategies (actions) that can be tested with the model. The dials depict the measures of the state of the system (indicators). Values for the indicators are calculated at each time-step during the period of the simulation.

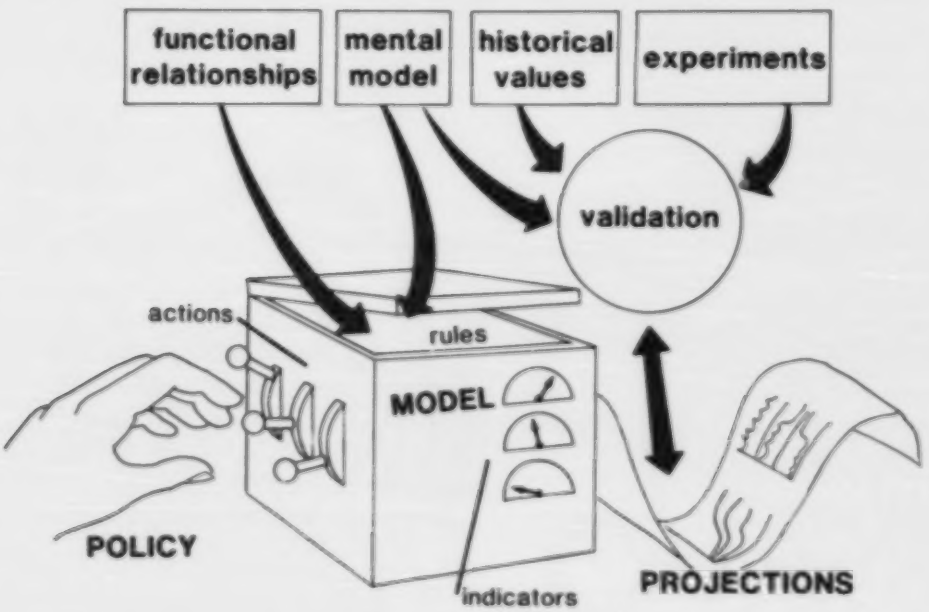

Figure 2. Modelling terminology

The OLCSM is designed to provide an objective measure of selected aspects of the environment, for a particular lake, under a given set of conditions. When new cottages are added to the existing stock, some change in the environmental indicator values is likely to occur. The amount of change that is considered acceptable is defined by the user, in the context of approved policies and standards.

2.3.1 SPATIAL AND TEMPORAL BOUNDARIES

A single lake, surrounded by a band of shoreland 50 metres deep, is the spatial unit selected for the OLCSM. Most of the submodels apply to an entire lake. However, smaller spatial units are needed for the Wildlife-Habitat submodel, so they are created by dividing the lakeshore and littoral zone into segments of uniform width. These wildlife segments are also used to identify the location of cottages and cottage lots.

Nutrient loadings from upstream and the immediate watershed are included in the model. Development on upstream lakes, land use within the watershed and size of the watershed are considered in the calculation of water quality indicator values. The model is structured so that chains of lakes can be evaluated. Beginning at the headwaters, the nutrient outflow from one lake is treated as nutrient input to the next lake downstream.

The time-step represents the increment of time between model calculations. In the present version, all submodels except Water Quality employ an annual time-step. In the Water Quality submodel, a seasonal time-step is preferable because phosphorus mass balance parameters can be estimated more accurately from seasonal data.

The length of each simulation is determined by the needs of the user and the implications of the data. For predicting the impact of cottage development, a 20-year simulation may be an appropriate period for planning purposes, but any time period can be selected. In order to simulate the retention of sewage-derived phosphorus in the soil around the septic system, it is essential to ensure that the time horizon for the simulation extends beyond the length of time the soil will retain its phosphorus-binding capacity.

2.3.2 INPUT AND OUTPUT (INDICATORS)

The submodel equations are designed to use data from existing records, such as the Ministry of Natural Resources creel census, maps and aerial photographs. The input consists of lake-specific data, such as the lake morphometry, lakeshore forest and littoral zone types around the lake, and locations of existing cottages, existing vacant lots and proposed cottage lots.

The model output consists of values for a set of indicator variables which function as gauges, or measures, of the response of the system. These values are plotted as graphs, or printed in tabulated form, for a user-specified interval of time and length of simulation. The indicators most useful to model users are those listed in Table 2.

Table 2. Principal indicators in the OLCSM

Number of lakeshore cottages
Total number of annual user-days for lake
Summer dissolved oxygen minimum
Winter dissolved oxygen minimum
Seasonal and mean ice-free lake phosphorus concentration
Algal biomass over ice-free months (wet weight)
Zooplankton biomass over ice-free months (dry weight)
Proportion of water samples with *Pseudomonas aeruginosa* pathogens
Maximum Sustained Yield (MSY) for smallmouth bass and lake trout
Fish carrying capacity of lake (by species)
Fish biomass (by species)
Fishing effort (by species and season)
Fish harvest (by species and season)
Population indices for small mammals and songbirds
Nesting habitat loss for hawks and loons
Mink activity index and disturbance factor

2.3.3 MANAGEMENT STRATEGIES (ACTIONS)

Selected management strategies, termed actions, may be introduced to mitigate the environmental impact of development. These actions pertain to parts of the ecosystem that can be managed and to modifications of the proposed development. They correspond to the controls a manager might exercise as part of a management policy. Actions can be taken to affect any aspect of the lake-watershed system. For example, changes may be made in the proposed plan of subdivision, the type of cottage access, the method of sewage disposal, or the length of the summer or winter fishing season. Management strategies included in the OLCSM are listed in Table 3.

The model is designed to indicate the future repercussions of various management options, to assist the user in choosing the most appropriate course of action for a particular lake. When several management scenarios have been simulated, the indicators from different scenarios can be compared and the most effective actions retained as a pool of viable management options.

2.3.4 SUBMODELS AND THEIR LINKAGES

The Ontario Lakeshore Capacity Simulation Model is divided into four subsystems, or submodels: Land Use, Water Quality, Fisheries and Wildlife-Habitat. Cottage use, identified as the major source of environmental impact from lakeshore cottage development, is predicted in the Land Use Submodel. Output from this submodel is then used in the Water Quality, Fisheries and Wildlife-Habitat submodels that calculate the environmental impact.

The Water Quality Submodel has two parts: one predicts the lake nutrient level, or trophic status, plus related water quality indicators, such as oxygen levels and transparency; the other is concerned with the health-related microbiology of lake water.

The Fisheries Submodel calculates the amount of fishing pressure, harvest and fish stock in a lake, in response to changes in the number of cottages, level of cottage use and number of anglers. The two sport-fish species included in the model are lake trout and smallmouth bass. The submodel is designed so that the lake trout are affected by reduced oxygen concentrations in the lake, whereas

Table 3. Management strategies in the OLCSM

LAND USE (COTTAGES)
Regulate cottage density
Require staged development for new subdivisions
Negotiate cottage construction rate
Discourage cottage conversion from seasonal to permanent use
Control type of access
Control size of common beach
Modify subdivision design to avoid interfering with critical wildlife habitat (e.g. adjust location of road, lot or beach)
WATER QUALITY
Limit phosphorus concentration in lake
Specify sewage system type and location for cottages
Require reduction of phosphates in sewage
FISHERIES
Shorten summer and/or winter angling season
Limit summer and/or winter catch
Encourage anglers to fish for underutilized species
Control public boat access
WILDLIFE-HABITAT
Reserve critical areas for deer, mink, loon, hawk and herptile habitat
Encourage cottagers to retain vegetation on lakeshore lots
Vary acceptable change in wildlife habitat

the smallmouth bass population changes in response to habitat alterations in the littoral zone.

In the Wildlife-Habitat Submodel, the impact of cottages on wildlife is calculated indirectly from changes in shoreland vegetation due to the development of cottage lots. This "habitat approach" emphasizes wildlife habitat disturbance. The wildlife included in the model are small mammals, songbirds, mink, loons, hawks, deer and turtles.

The linkages between the submodels represent the key interactions necessary for prediction of impact. The Land Use Submodel, for example, generates cottage-day and user-day data for all other submodels because these variables are a measure of cottage development, the source of the impact. Data on oxygen and lake phosphorus concentrations generated by the Water Quality Submodel and passed to the Fisheries Submodel reflect the linkages between water quality and fish biomass.

The overall framework for the OLCSM is illustrated in the flow diagram (Figure 3). Mathematical formulations and a fuller description of each submodel appear in the Integration report.

The methods of prediction used in each submodel of the OLCSM, which are drawn largely from the research results of the other Lakeshore Capacity Study components, are described in Part B (chapters 4-8) of this report.

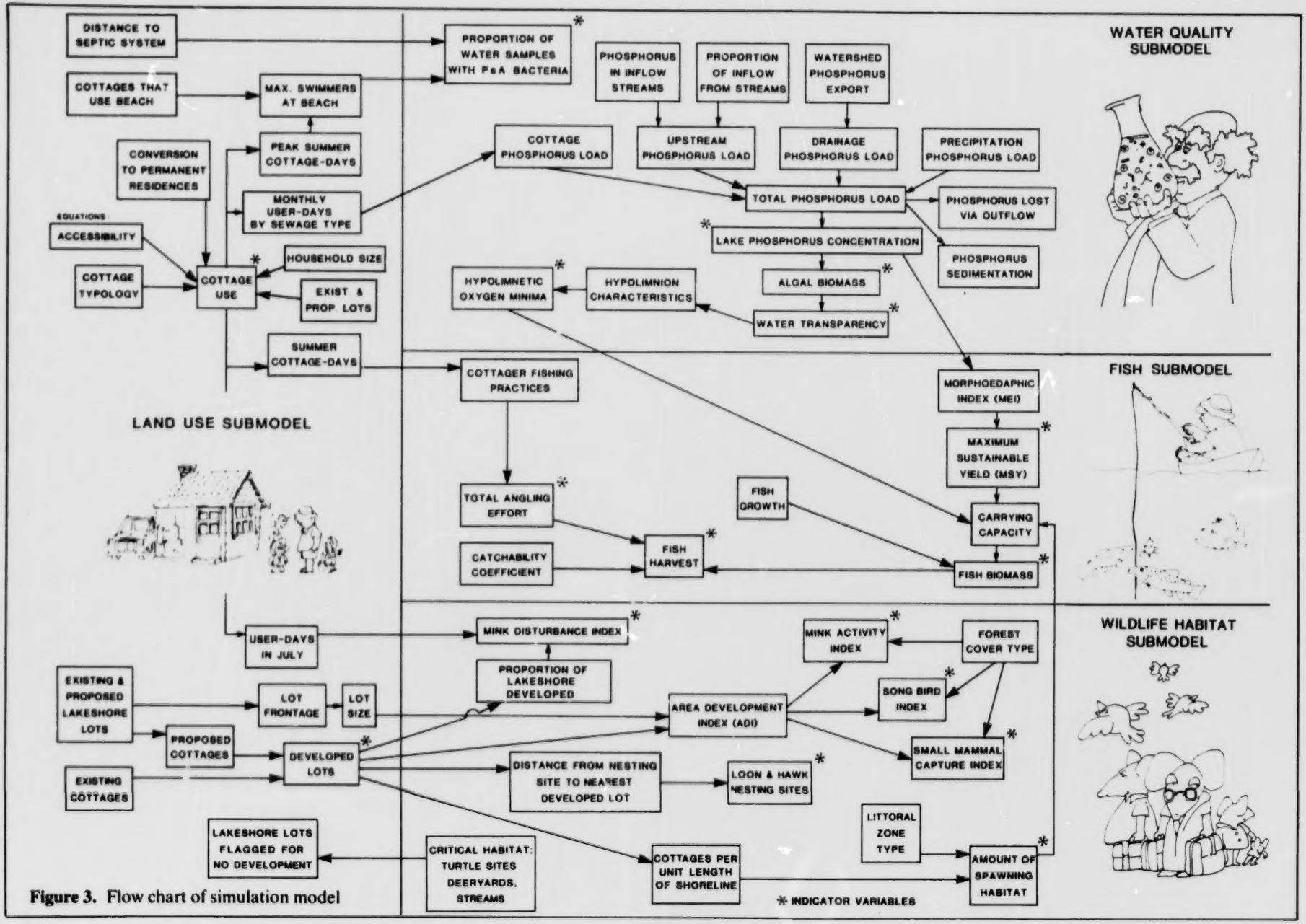

Figure 3. Flow chart of simulation model

3. POTENTIAL APPLICATION OF THE ONTARIO LAKESHORE CAPACITY SIMULATION MODEL

3.1 PRACTICAL APPLICATIONS IN THE PLANNING PROCESS

The aim of the Lakeshore Capacity Study was to produce a predictive model that could assist planners in the evaluation of subdivision proposals for cottage development on the shores of inland lakes. The Ontario Lakeshore Capacity Simulation Model not only fulfills this need but also has other potential applications in planning and resource management.

By providing predictions of the cottage capacities of different lakes, the model can assist regional planners in resolving demands for conflicting uses. While anglers may wish to have all lake trout fisheries protected, this may not always be feasible. Cottages may have to take precedence on some lake trout lakes. On others, it may be possible to resolve conflicts by introducing mitigative measures. How effective these measures may be can be tested by applying the simulation model.

The Land Use Submodel can be employed to predict where the greatest demand for cottages as principal residences is likely to occur. Such knowledge can assist planners in framing appropriate official plan policies and zoning regulations concerning cottage development. In addition, model predictions of the impact of different lot sizes on various wildlife species can assist in determining appropriate zoning standards for lot size.

Based on the location of the lake and the type of access, the Land Use Submodel can predict the user-days associated with cottages on a particular lake. Such a quantitative measure of the implications of different types of access on cottage use can assist planners in developing appropriate transportation policies in areas with inland lakes.

Whether roads to cottages are open in winter affects the lake trout fishery. For a specific lake, the simulation model can predict the effects of open or closed roads on the lake trout fishery, to assist planners and resource managers in recommending suitable snow clearing programs.

3.2 SOME CHARACTERISTICS OF THE ONTARIO LAKESHORE CAPACITY SIMULATION MODEL RELEVANT TO ITS PRACTICAL APPLICATION

While it is not the purpose of this report to explore the question of how the Ontario Lakeshore Capacity Simulation Model might be applied in the Ministry of Municipal Affairs, the description of the model would be incomplete if it failed to address in a general way some of the OLCSM characteristics that are relevant to its practical use.

The methods of prediction in the OLCSM were developed by researchers in the three ministries participating in the Lakeshore Capacity Study. Similarly, the

relevant data bases are lodged in these ministries. Therefore, input data for the OLCSM should be provided by the appropriate ministry. For example, the Ministry of Municipal Affairs should be responsible for the input data to predict cottage use; the Ministry of the Environment for data to predict the impact on water quality; and the Ministry of Natural Resources for data to predict the impact on fisheries and wildlife. Interpreting the predictions, keeping abreast of new scientific knowledge and monitoring the impact of new lakeshore development would also be the responsibility of the appropriate ministry.

The adaptive environmental assessment and management (AEAM) approach inherent in the Ontario Lakeshore Capacity Simulation Model works best when good liaison exists among planners, resource managers, scientists and policy advisors. While there are various ways of introducing the OLCSM, one approach might be to establish a small technical group, with representation from each of the three ministries. Together, the members of such an interdisciplinary team would have the knowledge necessary to operate the model, interpret the predictions and provide technical advice.

The OLCSM is not intended to be immutable. The present version of the model is capable of predicting the environmental impact of lakeshore cottage development and testing the effects of various mitigative measures. The next version should incorporate some or all of the refinements identified in the Integration report, to improve the accuracy of the predictions. The testing associated with refinements should include extreme situations, to ensure that the model is responsive to the full range of conditions in the Study Area. Subsequent versions of the OLCSM should reflect advances in scientific understanding of lake ecosystems and knowledge gained from monitoring the actual impact of new lakeshore development.

Finally, to view the OLCSM in proper perspective, it is essential to recognize that the methods of prediction are based on probabilities and that environmental predictions will always be based on incomplete scientific knowledge. While it may be tempting to seek greater precision, the crucial concern for planners is not whether the predictions are perfect but whether they are the best estimates of the future environmental repercussions of lakeshore cottage development. The OLCSM provides the best predictive methods presently available.

3.3 PREREQUISITES FOR OPERATING THE OLCSM

The operation of a computerized model, such as the Ontario Lakeshore Capacity Simulation Model, requires computer hardware, computer software and trained staff. Each of these essentials is described briefly in this section.

The OLCSM operates under a general purpose, time-sharing computer system. The model is controlled by the Simulation Control System (SIMCON) computer program, which handles input, output and record-keeping.

A computer terminal link to the computer system provides access to the model. With a graphics terminal, line graphs as well as tabulated output can be produced.

Operating instructions for the OLCSM are set out in the User's Manual (Teleki and Herskowitz, 1982). A "user-friendly" instruction program may be desirable for later versions of the OLCSM, to prompt the user regarding each entry.

To identify the staff skills required, a clear distinction must be drawn between operating the model, interpreting the predictions and refining the model. As the OLCSM responds to simple commands, a few weeks training is sufficient to learn what information to assemble, where to find it, how to enter it into the computer and how to generate predictions.

The predictions should be interpreted by specialists who have appropriate knowledge and experience. For example, the cottage use forecasts should be interpreted by planners in the Ministry of Municipal Affairs; water quality predictions by limnologists and microbiologists in the Ministry of the Environment; and fisheries and wildlife predictions by biologists in the Ministry of Natural Resources. One of the advantages of the OLCSM graphic output is that non-specialists can observe the trend lines formed from the predicted annual values of key indicators. However, only the specialists are qualified to interpret the predictions and to judge the effectiveness of mitigative measures.

Model refinement involves changes in the programming and coding. This demands both an understanding of the computer system and experience with simulation and environmental models.

PART B. RESEARCH RESULTS

4. LAND USE COMPONENT
5. TROPHIC STATUS COMPONENT
6. MICROBIOLOGY COMPONENT
7. FISHERIES COMPONENT
8. WILDLIFE COMPONENT

4. LAND USE COMPONENT

The goal of the Land Use Component planners and social scientists was to develop a method of predicting cottage use, for lakeshore cottages on a specific lake, prior to actual development.* The units of measurement chosen to describe the level of cottage use were termed cottage-days and user-days, where one "cottage-day" represents one cottage in use for one day, while one "user-day" represents one cottage in use for one day by one person.

Cottage use was important to the Trophic Status model because the number of people using the cottages affects the amount of phosphorous contributed to the lake and, in turn, water quality. Similarly, cottage use was important to the Fisheries Component net productivity model since the number of occupied cottages affects the number of anglers and, in turn, the amount of angling pressure exerted by cottagers on the fishery. Cottage use was also relevant to wildlife, as human activities associated with cottaging change the wildlife habitat on the lakeshore and, in turn, wildlife population and species.

4.1 EXISTING MODELS

A search of the literature in 1977 revealed no models that were specifically relevant to the task of predicting cottage use prior to development. While considerable work had been done relating to the use of cottages, much of it was descriptive rather than quantitative. Even in the latter category, while a number of studies produced estimates of annual cottage use, they did not identify the factors associated with different levels of use. Two exceptions are worth noting.

In the early 1970's, the Upper Great Lakes Regional Commission funded a study of lake property owners in northern Wisconsin (Klessig, 1973). The purpose was to learn more about the lake property owners, in order to determine their potential role in lake management. Reasons for variation in the time spent at the lake property were identified as the number of improvements on the property, age of the owner and location (rural or urban) of the owner's permanent residence. These three factors together explained 43% of the variance in the annual number of days at the lake.

In 1970, the College of Agriculture at Pennsylvania State University undertook a study of environmental quality aspects associated with seasonal home communities (Gamble et al., 1975). Most of the communities studied were located on lakes, with a few on the ocean or a bay. One of the objectives was to determine the attitudes of seasonal home occupants regarding environmental quality. Regression techniques were used to explain the reasons for the variation in annual use of the second home. The most significant variable was the seasons of the year the home was used — for each additional season, the use of the home increased by nine days. Also, older families and families who were willing to accept restrictions on their activities used their seasonal homes more. Lower use was associated with excessive noise, poor water quality and less emphasis on the quality of the home and community. Together, these variables explained 26% of the variation in seasonal home use.

* This chapter is based on the report Lakeshore Capacity Study, Land Use (Downing, 1986).

Some of the factors identified in these two studies as being associated with different levels of cottage use might assist in estimating the use of existing cottages. However, as explained in the following section, it was not feasible to employ them in attempting to predict cottage use at the planning stage, prior to actual development.

4.2 APPROACH TO DEVELOPING A MODEL TO PREDICT COTTAGE USE

The first step in developing a method of predicting cottage use prior to cottage construction was to recognize the stringent constraints on the choice of variables. As there would be no cottages or cottagers, no information would be available regarding improvements on the lot; number of seasons the cottage was occupied; family size, age or income; or attitudes and perceptions regarding noise or water quality.

The second step was to identify the kinds of information that would be available when a proposed subdivision was submitted for approval. The two major items were location of the subdivision and type of access to the cottage lots. Each of these was examined in the light of its potential as a predictor of cottage use.

The question of access offered several possibilities. If the time required to reach the cottage was a factor affecting cottage use, then any aspect of accessibility that would tend to increase or decrease the travel time might be relevant. One variable was the type of access, as some cottages had water access only. Another was the quality of the road. This could be measured in terms of road surface, as hard-surfaced roads had higher standards not only for surfacing but also for road width, curves and gradients, each of which could have some influence on travel time.

Given the location, it would be possible to measure the distance travelled on poor roads to reach the cottage. Similarly, the distance to urban centers in the region could be measured. Proximity to an urban center might tend to encourage longer stays at the cottage, due to the ease of replenishing supplies.

The 1978 Survey of Lakeshore Residents was designed to collect data from a representative sample of cottages on inland lakes in the Study Area, as a basis for model development. In total, 3,279 cottages received drop-off, mail-back questionnaires.

Information on cottage use pertained to the previous twelve months. The questionnaire included a calendar on which cottage owners were asked to record the number of people at the cottage on each day it was in use. From this detailed information, both cottage-days and user-days could be calculated, on a daily basis, for each cottage and each lake.

As the Lakeshore Capacity Study was concerned with the impact of cottages on the environment, it was essential to include cottages used all year as well as those used intermittently. Thus, the term "cottage" was used in a broad sense to include all single-family residential buildings located on the lakeshore or in close proximity to a lake. As most lakeshore development in the Study Area was single-tier development, most of the cottages had lake frontage.

Relevant information on the road network, type of cottage access and distance to urban centers was assembled in the summer of 1979 for the 1,139 cottages from which survey responses had been received. The data bank was completed in 1979, ready for the modelling process to begin in 1980.

4.3 RESEARCH RESULTS

4.3.1 COTTAGE USE

In general terms, the pattern of cottage use in Ontario was well known. It was widely recognized, for example, that summer was the period of greatest use, that winter use was increasing and that many cottages built originally for seasonal use were now being used all year. The 1978 Survey of Lakeshore Residents provided much more specific information for the Study Area. In particular, a record of the intensity of cottage use was obtained from the cottagers.

Of particular interest was the information on the number of days per year the cottage was used. It seemed logical to assume that the carrying capacity of the lakeshore would be greater for cottages used only part of the year than for those used all year. How much greater would depend in part on the amount of use.

A consistent seasonal pattern of cottage use was evident. Based on the monthly average for all cottages, the period of highest use extended for only two months, July and August; the period of lowest use extended for six months, from November to April. Transitional months occurred both in the spring (May and June) and in the fall (September and October).

The seasonal pattern of use was relevant to the analysis and prediction of cottage impact on the environment. It was apparent, for example, that cottagers could not be a major source of fishing pressure during the winter season, as few cottages were occupied at that time of year. Similarly, human disturbance of loons during their nesting period in June was probably limited, as cottages were not heavily used until July.

The daily use data (Figure 4) confirmed that there was a consistent weekly pattern of cottage use, not only during the summer but also throughout the rest of the year. More cottages were used on weekends than on weekdays. Further, more cottages were used on long weekends, such as the August Civic Holiday, than on other weekends.

While this information provided an illuminating overview of cottage occupancy, it did not link the use patterns to individual cottages. To do this, a statistical analysis was undertaken to develop a typology of cottages.

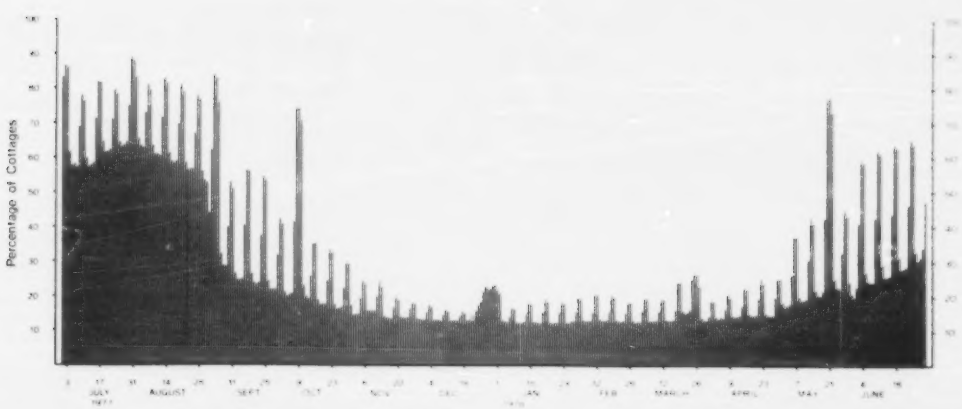

Figure 4. Percentage of cottages occupied daily during the year

4.3.2 COTTAGE TYPOLOGY

The initial purpose of the cottage typology was to classify the cottages according to their predominant use patterns, so the survey findings would provide a more realistic reflection of actual cottage use. It was known that the level of cottage use varied considerably, so it was not surprising that the overall average seemed unrealistically high to some cottage owners. Further, it was considered highly unlikely that every cottage was unique, so it was assumed that the cottages could be distinguished by their different use patterns and grouped accordingly. Cottage owners would then be able to identify a pattern of use similar to their own and the average annual use for that group of cottages would be much more likely to approximate their actual level of use.

The cottage typology analysis identified five mutually exclusive groups of cottages, each with similar use patterns. These are described below.

Group 1 ***Summer (July and August)***
Cottages used intensively during the summer (July and August) but much less at other times.

Group 2 ***Weekends***
Cottages used primarily on weekends in the spring, summer and fall.

Group 3 ***Long Weekends***
Cottages with low levels of use, except on long weekends in the spring, summer and fall.

Group 4 ***Extended Summer***
Cottages with high levels of use in the spring, summer and fall.

Group 5 ***All Year***
Cottages used all year, as a principal residence.

The five cottage typology groups had different average levels of annual cottage use and different average household sizes (Table 4). Cottages used all year, as a principal residence, were occupied about four times as much as those used predominantly in the summer (89 days) or on weekends in the spring, summer and fall (81 days). On average, cottages used all year had smaller households (2.56 persons) than those used predominantly in the summer (3.69 persons).

Table 4. Cottage use and household size for five cottage typology groups

Cottage Typology Group	Percent of Total Sample	COTTAGE USE Average Cottage-days per Year	HOUSEHOLD SIZE Average Persons per Cottage
Summer (July and August)	27.7	88.7	3.69
Weekends	28.0	80.5	3.60
Long Weekends	23.9	39.3	3.39
Extended Summer	7.8	175.2	2.64
All Year	12.6	363.1	2.56
All Cottages	100.0 (N = 1139)	116.03	3.07

4.4 MODELS TO PREDICT COTTAGE USE

The Land Use Component group considered several methods of predicting cottage use. One simple method, for example, was to assume that every cottage might be used all year. However, this "worst-case" assumption would drastically overestimate the actual level of cottage use, as the average use of a cottage in Muskoka-Haliburton (116 days during the year) was less than one-third of the maximum 365 days.

The implications of high predictions were considered. As the water in the lake is adversely affected by cottage use, the simulation model would respond to high cottage use estimates by forecasting lower water quality. In response to such a forecast, stringent limits would be placed on the creation of cottage lots, in order to preserve environmental quality. If this were to occur on many inland lakes, the effect on the total supply of cottage lots could be immense and the possibility of locating a cottage on the lakeshore could become more and more remote. In view of the implications, the "worst-case" approach was rejected.

Three methods of prediction were developed, which were termed the Averaging, Accessibility and Cottager models.

4.4.1 AVERAGING MODEL

In the Averaging Model, it is assumed that the average number of cottage-days recorded in the 1978 Survey of Lakeshore Residents would apply to all existing and proposed cottages. Thus, for a specific lake, total annual cottage use would be estimated by multiplying the number of cottages by 116 cottage-days.

The advantage of this method over the "worst-case" approach is its recognition of actual levels of cottage use. The predictions would tend to be realistic when averaged for all lakes.

The disadvantage of the Averaging Model is its inability to take into account variations in the average annual cottage use on different lakes and variations in the annual use of cottages on the same lake. Therefore, predictions of cottage use for a specific lake, using the Averaging Model, could be too high or too low.

4.4.2 ACCESSIBILITY MODEL

The predictive ability of the Accessibility Model is based on physical factors which measure the ease of access to the cottage. The major predictor is travel mode, which incorporates the type of access in summer and in winter. The other two predictors are the distance travelled on poor roads and the distance from the cottage to the nearest major urban centre in the region. Together, these variables explain 34% of the variance in annual cottage use.

Where the type of access is the same for each lot, the prediction of annual cottage-days for the subdivision is calculated by multiplying the predicted annual cottage-days per cottage by the number of lots (cottages) in the proposed subdivision. Where the type of access is different for some lots, those with the same type of access are grouped, a prediction is made for each group, and the separate predictions are aggregated, to provide a total for the whole development.

Conversion of the predicted cottage-days to user-days is accomplished by multiplying the predicted number of cottage-days for the subdivision by the average number of persons per cottage for the entire sample of cottages in the 1978 Survey of Lakeshore Residents. This "global" average (3.07 persons) is used for every subdivision.

The conceptual framework for the Accessibility Model is outlined in the flow diagram in Figure 5. The mathematical formulation of the model is provided in the Lakeshore Capacity Study Land Use report.

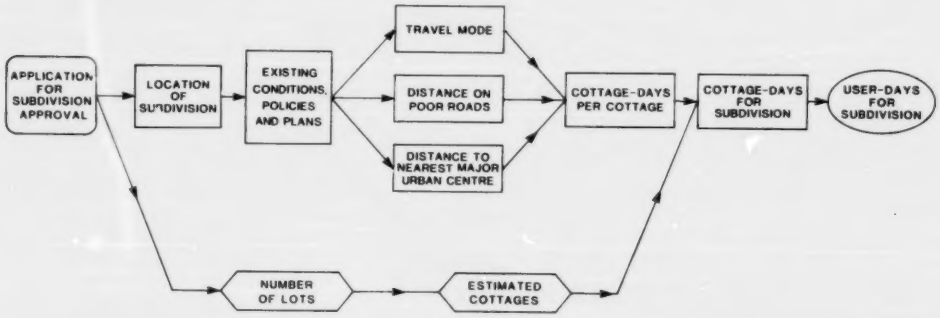

Figure 5. Accessibility Model: a conceptual diagram linking cottage accessibility and cottage use

The major advantage of the Accessibility Model is its ability to take into account variations in the average annual cottage use between lakes, by using as predictors accessibility characteristics associated with cottage use. Similarly, variations in cottage use between cottages are taken into account by predicting separately for groups of cottages with different types of access. Thus, the predictions for specific lakes are likely to be more accurate than those from the Averaging Model.

Another advantage of the Accessibility Model is that it stretches into the future as far as possible by employing Official Plans and Transportation Plans as a source of information for coding all the variables. In this way, proposed new roads, road improvements and realignments are built into the model to the degree to which they can be predicted at the time the model is applied.

The Accessibility Model is objective in the sense that all variables can be measured; relatively simple to apply because it employs only five predictor variables; and efficient in achieving good results with minimum effort.

4.4.3 COTTAGER MODEL

The pattern of cottage use recorded for each cottage in the 1978 Survey of Lakeshore Residents can be thought of as the end result of all the decisions made by cottagers regarding their use of the cottage. When viewed in this way, it is evident that the five distinct cottage groups identified in the cottage typology provide a valid basis for predicting cottage use, as they reflect not only decisions which may be influenced by the socio-economic characteristics of the cottage owners but also decisions in response to changes in external factors, such as fuel costs.

Initially, the Cottager Model was based on the five groups in the cottage typology. However, as the regression coefficients for the three low-use groups Summer (July and August), Weekends and Long Weekends were similar, they were combined into one Seasonal group in order to simplify the equation. This reduced the total number of cottage groups to three, namely Seasonal, Extended Summer and All Year.

These three groups of cottages differ substantially in their average annual cottage-days, the dependent variable in the Land Use Component models. The Seasonal group averages only 71 cottage-days per year, while the All Year group averages 363 cottage-days per year (Table 5). Between these extremes is the Extended Summer group, comprising cottages which are occupied for 175 cottage-days, on average. These differences give the model its predictive power.

Table 5. Cottage use and household size for three cottage typology groups

Cottage Typology Group	Percent of Total Sample	COTTAGE USE Average Cottage-days per Year	HOUSEHOLD SIZE Average Persons per Cottage
Seasonal*	79.5	71.0	3.57
Extended Summer	7.8	175.2	2.64
All Year	12.6	363.1	2.56
All Cottages	100.0 (N = 1139)	116.03	3.07

* Includes Summer (July and August), Weekends and Long Weekends typology groups.

The Cottager Model includes two cottage typology variables, Extended Summer and All Year, plus three accessibility variables. Although all the regression coefficients in the equation are highly significant, the variables representing cottage groups are the most reliable predictors.

As the values for the cottage typology groups will not be known when the model is applied, they must be derived from one of the benchmark lakes. These are, by definition, lakes where the cottage typology is known, so the only lakes which qualify are those included in the 1978 Survey of Lakeshore Residents. In addition, each benchmark lake must have a sufficient number of respondents to allow each typology group to be represented. Accordingly, the pool of candidate benchmark lakes comprises 36 lakes.

To select a specific benchmark lake, the goal is to find the best possible match in cottage typology between the target lake and its benchmark lake. Objective criteria are provided in the Land Use report to assist in choosing an appropriate benchmark. Recognizing that the strongest predictor in the Cottager Model is the proportion of cottages in the All Year typology group, the criteria suggest ways of using planning policies and zoning regulations as sources of information with respect to seasonal versus permanent use.

The conceptual framework for the Cottager Model is outlined in the network diagram in Figure 6. The mathematical formulation of the model is provided in the Lakeshore Capacity Study Land Use report.

The predictive power of the Cottager Model is extremely high, theoretically. When the cottage typology is known, the model explains 92% of the variance in cottage use among the cottages in the survey sample. However, when benchmarking is introduced, which is required in practice, a drastic reduction in

accuracy occurs. While there is no way of measuring it precisely, the Cottager Model appears to predict cottage use within a range of accuracy similar to the Accessibility Model.

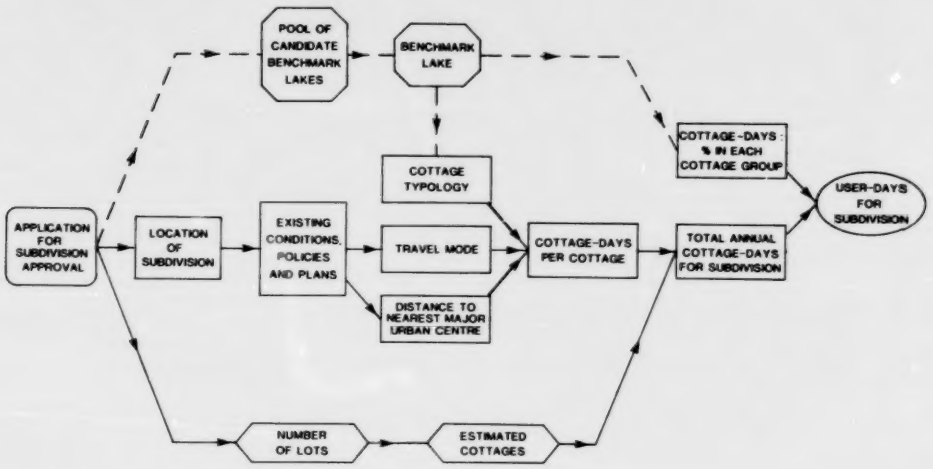

Figure 6. Cottager Model: a conceptual diagram linking cottage typology and cottage use

4.4.4 SELECTING THE BEST PREDICTION

The Land Use Component group tested predictions of cottage use generated by the three models, by comparing them with actual survey data. It was clear from the test results that the Accessibility and Cottager models performed better than the Averaging Model. As there was no statistical support for choosing between the Accessibility and Cottager models, the Land Use Component team recommended that both be employed. This would have the advantage of predicting on the basis of two different sets of information — one related to ease of access to the cottage and the other to patterns of cottage use.

The higher prediction of cottage use was recommended for use in the OLCSM. It more closely approximated actual cottage use where the travel mode was "car all year" and where the All Year typology group included a high proportion of the cottages. In other situations, the higher prediction tended to overstate cottage use, thereby providing some margin of safety while still remaining within a realistic range.

Particular care is required in designating the "travel mode" correctly, as it affects not only the predictive ability of the Accessibility Model but also the accuracy of the benchmarking which, in turn, affects the predictive ability of the Cottager Model. While several objective criteria are provided to assist in selecting an appropriate benchmark lake, some subjective judgement must be exercised. For this reason, application of the Land Use Component models requires professional knowledge of planning policies and regulations and their implications with respect to future development. Therefore, it is recommended that responsibility for the models remain with the Ministry of Municipal Affairs, which is responsible for administration of the Planning Act.

The derivation of the models is described more fully in the Land Use report. In addition, the Land Use Component models are described in the context of the Lakeshore Capacity Study as a whole in the Integration report.

5. TROPHIC STATUS COMPONENT

The Trophic Status Component research was designed to test and refine existing models for estimating the effects of lakeshore development on the trophic status of lakes.*

In essence, the trophic status of a lake is its capacity to sustain the growth and reproduction of plant and animal life. Phosphates, nitrates and other chemical substances, which leach into a lake from its watershed, serve as food or nutrients for a host of microscopic plants (phytoplankton). These plants drift in the lake water, providing food for minute animals (zooplankton and bottom fauna) which, in turn, are eaten by small fish.

Lakes with low concentrations of nutrients are said to be oligotrophic; those with high concentrations of nutrients are eutrophic; and those in an intermediate state are described as mesotrophic. Lakes located in the sparse soils and granitic rocks of the Precambrian Shield tend to be oligotrophic, while those in regions with deep glacial overburden and limestone bedrock are usually mesotrophic or eutrophic.

As phosphates and other plant nutrients accumulate in a lake, it may change from oligotrophic to mesotrophic and, subsequently, to eutrophic. Under natural conditions, such a process of change could take thousands of years. However, human activity on the lakeshore or in the watershed may accelerate the process if, for example, nutrients enter the lake in runoff from agricultural land or in seepage from waste disposal systems serving lakeshore cottage development.

5.1 EXISTING TROPHIC STATUS MODELS

The trophic status of a lake is usually determined by measuring specific water quality characteristics, such as chlorophyll *a* concentration (a surrogate measure for phytoplankton biomass), water clarity and the rate of oxygen loss from the profundal waters. It is well known that phosphorus, the algal nutrient present in shortest supply, controls the trophic status of most Precambrian Shield lakes because of its relationship with algal biomass and production.

The conceptual model (Figure 7) linking lakeshore development, lake morphometry, the hydrologic and phosphorus budgets, and the trophic status of a lake was originally outlined by Dillon and Rigler (1975). Inherent in the model was a critical untested assumption that lakeshore development using septic systems for waste disposal contributed phosphorus to the lake. In addition, many of the models were developed on the basis of data collected from a large number of lakes all over the world, which had a much wider range in trophic status than is typically found in lakes in the Precambrian regions of Ontario. As the existing models could not provide predictions with an acceptable degree of confidence over this smaller range in trophic conditions, it was necessary to undertake further model development, refinement and testing.

* This chapter is based on the report Lakeshore Capacity Study, Trophic Status (Dillon et al., 1986).

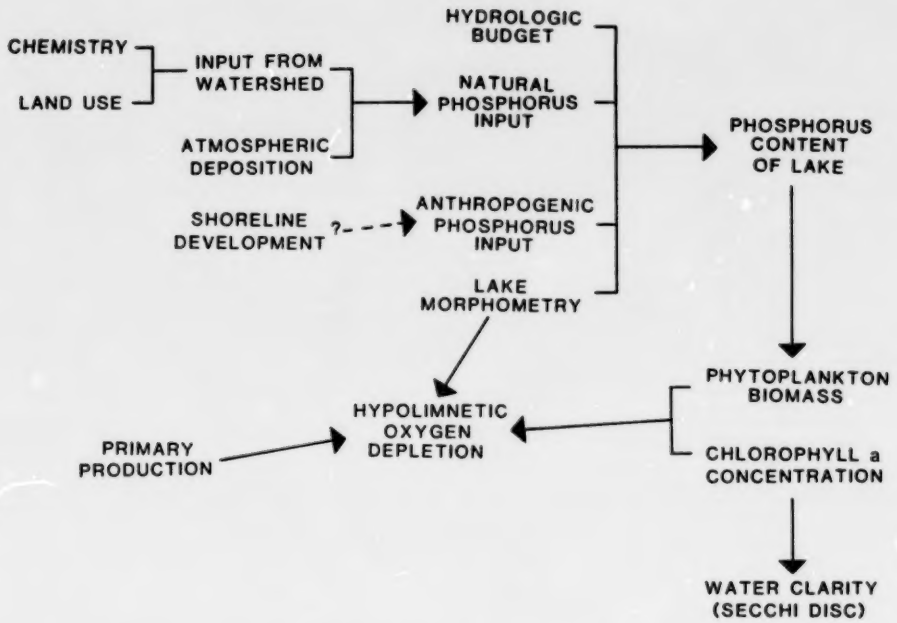

Figure 7. Conceptual model of the relationships linking phosphorus and the trophic status of lakes

5.2 STUDY DESIGN

The Trophic Status Component limnologists used two approaches in addressing the question of whether cottage development on the lakeshore contributed phosphorus to a lake.

In the first approach, the natural phosphorus and hydrologic budgets were measured for six lakes ("A" lakes) which exhibited a wide range in the potential significance of lakeshore cottages to the phosphorus budgets. Existing trophic status models were calibrated, using the two **undeveloped** "A" lakes; the models were then applied to the four **developed** "A" lakes. Differences between measured phosphorus concentrations in the developed lakes and phosphorus concentrations predicted from the calibrated existing models were assumed to be attributable to anthropogenic phosphorus inputs which, in turn, were quantitatively related to the extent of lakeshore development.

In the second approach, the intention was to compare the trophic status of nine lakes where lakeshore development was proposed ("B" lakes), before and after cottage construction. In fact, few of the anticipated changes occurred during the course of the Lakeshore Capacity Study, so such a comparison could not be made. Nevertheless, data collected from the "B" lakes contributed to the research, as the independent data set was used for testing models developed from the "A" lakes.

In addition, nine terrestrial watersheds ("export" watersheds) were selected for study, in order to broaden the range of geological characteristics considered.

5.3 APPROACH TO EVALUATING THE EFFECTS OF LAKESHORE COTTAGE DEVELOPMENT ON THE TROPHIC STATUS OF LAKES

As natural soil deposits around the lakes vary widely in their ability to assimilate phosphorus discharged from septic tile beds, the findings from a few study sites cannot be extrapolated with confidence to the entire lakeshore. Thus, direct measurement of the influence of lakeshore development on the trophic status of lakes is extremely difficult. To overcome this problem, the Trophic Status Component limnologists used two indirect approaches, involving comparisons between the developed and undeveloped lakes with respect to (i) their nutrient regimes and (ii) several biological characteristics.

Of the six intensively studied "A" lakes, two had little or no development on the lakeshore or in the watershed, while the other four had a significant amount of development. However, due to natural variations in the nutrient content of undeveloped lakes, a direct comparison of the phosphorus (or other nutrient) content of the developed and undeveloped lakes was not a valid approach for measuring the effects of development. Fortunately, conceptual links between lakeshore development and the phosphorus budget of a lake were well established. Hence, it was possible to formulate the conceptual model in mathematical terms, calibrate it using the undeveloped lakes, and then apply it to the developed lakes to ascertain the effects of lakeshore development on the phosphorus budget and thus on trophic status.

Several biological components of the developed lakes were compared directly with the same components of the undeveloped lakes. These biological components included phytoplankton, zooplankton and macrophytes. While natural differences in trophic status confounded the interpretation of community data, restricting the usefulness of this approach, direct comparison did allow implicit evaluation of the influence of lakeshore development on biological communities that were not related to changes in nutrient supply.

5.4 THE PHOSPHORUS BUDGET APPROACH

Factors that determine the total phosphorus concentration in a lake include lake morphometry, the hydrologic budget, phosphorus input and the phosphorus loss rate. The conceptual model linking these factors was presented in Figure 7.

The morphometry of each of the "A" lakes, including lake area, volume, mean and maximum depth, and length of the shoreline, was measured at the beginning of the study. The hydrologic budgets of the "A" lakes were measured directly for the four-year period June 1976 to May 1980. The components of the hydrologic cycle are related by the water balance equation, which states that the change in lake volume is equal to precipitation to the lake surface plus surface runoff into the lake minus outflow and net evaporation from the lake. Water balances were constructed for four consecutive 12-month periods, beginning in June 1976, and for the entire four-year period. Because each term in the water balance equation was measured directly, it was possible to evaluate the accuracy of the hydrologic budgets.

Total phosphorus inputs from all significant sources, other than those associated with lakeshore development, were measured for the same four-year period. The measured sources included atmospheric deposition and watershed runoff (Figure 8).

Loss of phosphorus by outflow from each lake was also measured, for the same four years. Loss of phosphorus by sedimentation within each lake required quantification but the rate of accumulation of phosphorus in the sediments of lakes is difficult to measure independently. It is possible to calculate the phosphorus sedimentation rate by difference between the total input rate and the loss rate attributed to outflow, if corrections are made for changes in phosphorus concentration in the lake. This method is suitable for the **undeveloped** lakes only, since the actual total input is unknown for the developed lakes. A general sedimentation rate model or an independent measurement of sedimentation rate was therefore needed.

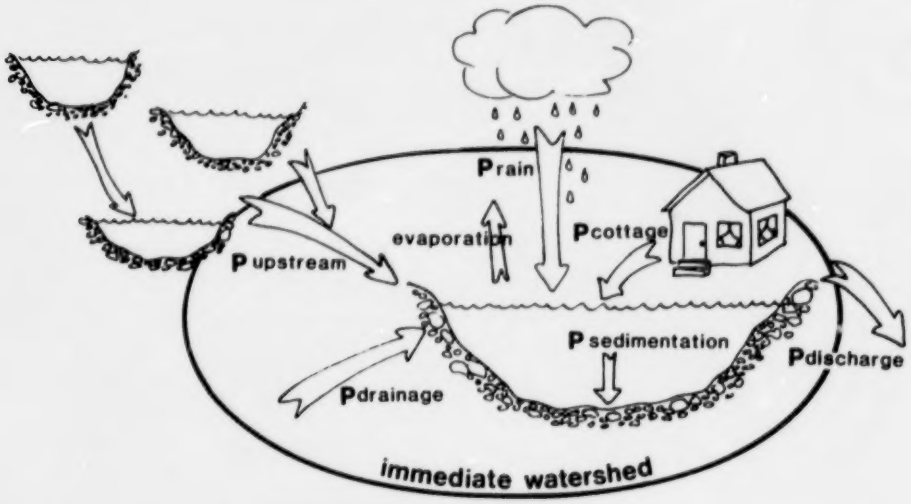

Figure 8. Phosphorus input and output

5.5 RESEARCH RESULTS

The major findings of the Trophic Status Component group regarding the hydrologic and phosphorus budgets of the "A" lakes are summarized below.

Hydrologic budgets, which were calculated for four annual periods (June to May) and for the entire four-year period (1976-80), balanced to within ± 10% for five of the six "A" lakes. This gave confidence in the individual supply and loss terms and in the use of the data for constructing chemical mass balances and calculating water replenishment times for the lakes.

A wide range in annual atmospheric deposition of phosphorus was apparent, indicating that long-term monitoring was essential in order to obtain reliable estimates. A seasonal pattern in the deposition of phosphorus was observed, with peak values occurring in the summer months. Deposition rates at different locations did not vary significantly.

The four-year phosphorus export (yield) for 30 watersheds varied widely from one watershed to another. The grand mean phosphorus export for metamorphic watersheds was somewhat higher than the mean based on previous studies. Year-to-year variability in yield was not significant compared to site-to-site variability.

Based on a literature review, the average phosphorus supply to sewage disposal systems was calculated to be 0.8 kilograms per person per year. Phosphorus retention in the sewage disposal system was estimated for different types of systems in use around the study lakes. Based on these estimates, phosphorus retention in septic tank and tile field systems was assumed to be zero unless information was available on the condition of the system and the type of soil, in which case a correction factor for phosphorus retention in the soil could be applied. Information on the levels of cottage use and the types of sewage disposal systems, obtained from the Land Use Component, allowed the potential anthropogenic phosphorus input to each study lake to be estimated. These figures ranged from zero to 83 kilograms of phosphorus per year.

Loss of phosphorus to the lake sediments was calculated for the undeveloped lakes in three ways: from measured phosphorus mass balances; from sediment trap data; and from information on the concentration of phosphorus in sediments and the sediment accumulation rate. When the results were compared, it was evident that sediment traps overestimated the phosphorus sedimentation rate, whereas the sediment chronology method provided results comparable to those from the mass balances method.

The Trophic Status Component scientists also investigated minor components of the phosphorus budget. Based on data from one lake, net phosphorus loss by fish harvest was estimated at 2% of the total phosphorus supply; phosphorus loss by emerging insects was negligible; and phosphorus supply from forest litterfall was estimated at 3%of the total phosphorus input.

Using phosphorus mass balance information, the relative importance of the various sources of phosphorus was evaluated. Inflowing streams varied widely in importance, providing from 0.4% to 69% of the natural phosphorus input to the lakes. Precipitation was the single most important source of phosphorus in four of the six "A" lakes, contributing 20% to 74% of the total natural supply (1976-80 mean values). Contributions from the ungauged watersheds were relatively small, averaging 15% of the total natural supply of phosphorus to the lakes. The loss of phosphorus to the sediments was always greater than the loss to the lake outlet, even when potential anthropogenic inputs were not considered. Finally, the potential contributions from anthropogenic sources of phosphorus ranged from zero to 55% of the total phosphorus supply. Substantial year-to-year variability in individual components of the phosphorus budgets indicated that mass balances must be measured for several years in order to develop and validate trophic status models.

The impacts of lakeshore development on communities of phytoplankton, zooplankton and macrophytes were evaluated on the "A" and "B" lakes. This was done by examining the correlations between parameters describing the state of the biological communities and indices of lakeshore development or by comparing the values of the parameters for sets of lakes with extremely different intensities of cottage use. When phytoplankton community parameters for the three most developed lakes and the four undeveloped lakes were compared, there was no significant difference between the two sets of lakes. A similar comparison for zooplankton community parameters (1977-79) showed no significant difference between lake sets. Further, no detectable difference was found in the composition, standing stock or nutritional status of macrophytes in eight lakes covering the full range of human use. Thus, there was no evidence of any direct relationship between lakeshore development and these aquatic biota.

5.6 MODELS TO PREDICT TROPHIC STATUS

The Trophic Status Component scientists started from a strong base in Phase III of the Lakeshore Capacity Study. A conceptual model and several mathematical models were already available to assist in predicting the effects of lakeshore cottage development on the trophic status of a lake. Accordingly, in Phase III, existing models were refined and new models were developed to strengthen and link individual parts of the conceptual model.

The resulting models include those for the prediction of: (1) important components of the hydrology of lakes and watersheds; (2) yield or export of phosphorus from terrestrial watersheds; (3) retention of phosphorus in the lake sediments; (4) concentration of phosphorus in a lake; (5) phytoplankton biomass and chlorophyll *a* levels; (6) water clarity (as measured by Secchi disc); (7) zooplankton biomass; and (8) depletion rate of oxygen from the profundal waters. These models are described in general terms below.

Existing models predicting the four principal hydrologic components (precipitation, runoff, evapotranspiration and evaporation) from readily obtainable hydrometeorological data were refined and tested on the "A" lakes and "export" watersheds. Precipitation at a given site could be predicted, using data from nearby meteorological stations. Of the five techniques investigated to predict runoff, the preferred method was the modified Tennessee Valley Authority (TVA) model because it allowed prediction of streamflow on a fine time-scale (daily) for any given set of climatic conditions. After calibration on the "A" lake watersheds, the modified TVA model was tested on the "export" watersheds and gave good predictions of daily flow in all years except 1977-78. Both basin evapotranspiration and lake evaporation could be predicted, using climatological models.

Two models were developed to predict the annual yield of phosphorus from terrestrial watersheds. In one model, 51% of the variance in the phosphorus yield of 30 watersheds was related to geologic, land use and hydrologic characteristics of the watershed. In the other model, 46% of the variance in the phosphorus yield was explained by geologic and land use characteristics alone.

The relationship given in Dillon et al. (1977) successfully predicted the annual retention of phosphorus from the areal water load, when tested against estimates derived from the phosphorus mass balances in two undeveloped lakes. The model was recalibrated for anoxic (oxygen deficient) lakes, resulting in an adjustment of the phosphorus settling velocity.

An existing model for predicting the concentration of phosphorus in lakes at spring turnover was refined to allow prediction of phosphorus in any season and to incorporate the relation between the concentration of phosphorus in the lake and that in the lake outlet. In lakes with no anthropogenic input of phosphorus, the predicted and observed mean (1976-80) concentrations of phosphorus during the ice-free season agreed, giving confidence in the use of the model in lakes with anthropogenic inputs of phosphorus. Incorporating thermal stratification in the model did not improve its predictive capability.

Using the revised phosphorus retention and concentration models, predicted and observed concentrations of phosphorus were compared for the four "A" lakes with lakeshore development and the fraction of the potential anthropogenic phosphorus input to the lakes was calculated. For three lakes, the predicted and observed phosphorus levels agreed, if it was assumed that 100%

of the anthropogenic phosphorus supply entered the lakes. However, for one lake, only 20% of the anthropogenic phosphorus supply must enter the lake for the observed and predicted phosphorus levels to agree. This may be due to differences in the phosphorus retention capability of the soils surrounding the lake.

Models were developed from the "A" and "B" lake data to predict phytoplankton biomass, corrected phytoplankton biomass (excluding diatoms) and the concentration of chlorophyll *a* (a correlate of phytoplankton biomass) during the ice-free season, from epilimnetic concentrations of algal nutrients (1976-80 mean values). Diatoms were excluded from the "corrected" phytoplankton biomass in part because many diatom species contain a relatively large empty space but also because of the difficulty in distinguishing between living and dead diatoms. Chlorophyll *a* and corrected phytoplankton biomass could both be predicted from the concentration of phosphorus and the ratio of the concentration of nitrogen and phosphorus. The phytoplankton biomass was related to the concentration of total organic nitrogen. Including total zooplankton biomass or herbivorous zooplankton biomass in the relations did not improve their predictive ability.

Water clarity (as measured by Secchi depth) of the "A" and "B" lakes during the ice-free season was controlled by the dissolved organic carbon content (or colour) of the lakes. Chlorophyll *a* concentration and phytoplankton biomass were not strongly correlated with water clarity.

Models for predicting areal hypolimnetic oxygen rates were tested. The Cornett-Rigler model (Cornett and Rigler, 1979), when recalibrated with data collected in this study, provided the closest agreement between predicted and observed depletion rates.

Total crustacean zooplankton biomass and herbivorous zooplankton biomass of the "A" and "B" lakes (1977-79 mean values) could be predicted from the whole-lake concentration of phosphorus during the summer stratified period. These predictions may be useful in future efforts to model fish biomass.

Acidic deposition, a result of the oxidation and hydrolysis of sulphur and nitrogen oxides released as a product of fossil fuel combustion or the smelting of sulphide ores, may be the single most significant environmental problem in eastern North America. Lakes on the Precambrian Shield are particularly sensitive to the deposition of these strong acids. As loading rates of acids in the Study Area are as high as those in any area of the world, the Trophic Status Component analysis was designed to ascertain whether nutrient - trophic status relationships were influenced by acidic deposition. The chlorophyll *a*, phytoplankton biomass and water clarity models were derived with consideration of both nutrient enrichment and acidification parameters. The analysis produced no evidence that the pH of the lakewater, which is an indicator of acidity, affected the nutrient - trophic status relationships in the study lakes.

Relationships among the models developed by the Land Use, Trophic Status and Fisheries components are described in the Integration report, in the context of the Lakeshore Capacity Study as a whole. Mathematical formulations of the trophic status models appear in the Trophic Status report, where their derivation is described more fully.

6. MICROBIOLOGY COMPONENT

The goal of the Microbiology Component research was to define and quantify the influence of lakeshore cottage development on the bacteriological quality of the lake water and infections among human users of the water.*

The need for adequate treatment of drinking water and sewage in a cottage development is well documented in the literature. In Ontario, the policies and practices of the Ministry of Health and the Ministry of the Environment minimize the possible presence of disease-causing organisms in the drinking water supply and the contamination of the environment with sewage. The Ministry of the Environment and the various medical authorities have an effective procedure for determining whether improperly treated sewage is creating a health hazard, thus requiring immediate remedial action. Therefore, the Microbiology Component group directed their Lakeshore Capacity Study research toward swimming-related illnesses that were less well understood and documented.

While human illness due to swimming has been relatively uncommon, several serious outbreaks of bacterial and viral infections have been reported. The types of human disease associated with swimming include gastrointestinal illness, wound infections, and infections of the eyes, ears, nose, skin and throat by a variety of bacteria and viruses. Of these, the ear infection *otitis externa* or "swimmer's ear" accounts for the majority of swimming-related illnesses. It is a painful ear infection requiring medical diagnosis and treatment.

Infectious microorganisms found in recreational waters can come from one of three sources: pollution by human or animal sewage, the washing of the skin of bathers, or the resident population of environmental microbes. The last is generally not controllable but seems to play a minor role in causing human disease. For the other two, the contribution of the infectious agent to the recreational waters depends on such factors as the level of illness in the contributing population, the number of carriers of the agent and the effective countermeasures introduced.

The probability of an ill individual or a carrier being present in small populations, such as the bathers from a few cottages, is correspondingly small. Under these circumstances, the occurrence of the infectious agent will be sporadic, so the normal indicator systems may fail. However, by determining the concentration of the pathogen directly, this problem can be alleviated. Accordingly, the research undertaken by the Microbiology Component scientists was designed to examine the relationship of the pathogen *Pseudomonas aeruginosa* to the ear infection *otitis externa*.

* This chapter is based on the report Lakeshore Capacity Study, Microbiology (Burger, 1983).

6.1 PSEUDOMONAS AERUGINOSA - OTITIS EXTERNA

Pseudomonas aeruginosa is the primary organism associated with the external ear infection *otitis externa*. According to the literature, *P. aeruginosa* occurs mainly in humans.

As an infectious agent, *P. aeruginosa* has been described as an opportunistic pathogen. It may be present without apparent illness or disease but if the resistance of the host is reduced by trauma, other disease, medication or predisposition, a secondary infection by *P. aeruginosa* can occur.

Although a direct correlation has not been established between ear infections and waterborne *Pseudomonas aeruginosa*, the reported incidence of *otitis externa* is higher among swimmers than non-swimmers. Ear infections due to *P. aeruginosa* may even occur with low densities of pathogens in the water.

When a swimmer submerges his head in water containing *P. aeruginosa*, a small but definable portion of water enters the ear canal, carrying the pathogen with it. This water, with its bacterial content, may either drain out or be dried out without any further action or it may moisten the ear canal contents and remain for a considerable time. The bacteria may also either settle out or adhere to the inner surfaces even though the water is removed. Once the *P. aeruginosa* has entered the ear, an infection can occur. However, the process by which the infection occurs is not clearly understood.

6.2 FIELD SURVEYS

The Microbiology Component field work included two types of survey. One involved regular sampling surveys of lakes to determine the distribution and densities of bacteria and the levels of important nutrients. These were designed to provide information concerning the effects of development on bacteriological water quality and on possible relationships between lakeshore development, bacterial densities and nutrient status. The other type of survey was an epidemiological investigation of *P. aeruginosa* - related ear infection among users of shoreline waters and beaches.

The beach studies involved several kinds of data. Information was gathered relating to the history of ear infection, swimming habits and water-based recreational activities of cottagers and swimmers. Samples of bathing beach waters and shoreline sediments were selected and analyzed for indicator bacteria and *Pseudomonas aeruginosa*. The ears of swimmers were swabbed prior to and just after swimming. Swab cultures were then analyzed for *P. aeruginosa* and the results from the pre- and post-swimming swabs compared.

Data from the lake and beach surveys were analyzed to identify relationships between the incidence of *otitis externa*, bacterial and chemical water quality, levels of human use of the water (swimmer load), and environmental conditions.

6.3 RESEARCH RESULTS

All the evidence from the Microbiology Component research suggested that a relationship existed between *P. aeruginosa*, the number of people using the beach, and the water temperature, but the relationship could not be validated statistically.

Based on the results reported in the literature and the findings of their study, Microbiology Component scientists placed values on the levels of occurrence of

Pseudomonas aeruginosa. About 10% of the normal healthy human population carry *P. aeruginosa* in their gastrointestinal systems. As a result, the pathogen is present in human sewage.

In north temperate surface waters which are not affected by humans, the *P. aeruginosa* levels are extremely low. Where human activity occurs, such as at a beach with public access, the pathogen can be measured. The levels of *P. aeruginosa* tended to increase as the number of beach users increased.

The time trend of *Pseudomonas aeruginosa* found in swimmers' ears followed closely that of *P. aeruginosa* found in the water. During the period mid-July to mid-August, when lake water temperatures rose to 24° or 25°C, *P. aeruginosa* was recovered more frequently.

While *Pseudomonas aeruginosa* is found in a low percentage of normal, healthy ears, Microbiology Component data showed higher percentages when measured after swimming. Up to 3% of the swabs from healthy swimmers' ears before swimming and up to 8% of the swabs after swimming were positive for *P. aeruginosa*. The only source of the new *P. aeruginosa* in the ears was water contaminated with the pathogen, which entered the ear while swimming.

The *otitis externa* ear infection occurred in 7% to 12% of the swimmers. The swimmers most likely to contract an infection were those in the age group 5 to 24 years, those who swam frequently, and those with a previous history of ear infection.

These data show that if the water in a swimming area contains *Pseudomonas aeruginosa*, swimming activity will introduce the pathogen into the swimmer's ear. Whether the *P. aeruginosa* will cause an ear infection will depend on a number of medical circumstances, which are beyond the scope of this study.

6.4 RECOMMENDATIONS

The importance of adequate treatment of the water used for drinking, washing and food preparation, and of the sewage from cottages, cannot be stressed strongly enough. In the examination of any proposal for development, these areas must be considered if the health of the people is to be safeguarded.

In this study, the research was restricted to one organism, *Pseudomonas aeruginosa*, and one disease, an ear infection called *otitis externa*. The model developed by the Microbiology Component (Figure 9) is supported by the general microbiological literature, by the general inclination of microbial ecology and by the findings of the Microbiology Component scientists. It is a qualitative model with some sections having quantitative data.

The results and the model provided a basis for the following recommendations of the Microbiology Component with respect to a *P. aeruginosa* water quality criterion for use in Ontario and criteria for the location and design of swimming areas in order to minimize the risks of *otitis externa* ear infections.

The incidence of ear infections among swimmers at a particular location increased noticeably when the 75 percentile concentration of *P. aeruginosa* exceeded 10 bacteria per 100 mL. This level of bacterial contamination can, therefore, be set as a water quality criterion. When the *P. aeruginosa* concentrations in a swimming area regularly exceed this level, the risk of contracting an ear infection is greater and the use of the swimming area should be restricted until the situation has been rectified.

A swimming area associated with a cottage development should be located upstream and away from possible sources of sewage and sewage impacted soil runoff. It should also be located away from shallow, organically rich, marshy areas which may be warmed by the sun or by a thermal input. In addition, it should be designed to ensure good flushing or dilution with water from outside the impacted area.

Swimmers should be dispersed over as wide an area as possible, to reduce swimmer loading, the *P. aeruginosa* levels in the water and, in turn, the likelihood of *otitis externa* ear infections.

The Microbiology Component work is described more fully in the Microbiology report. In addition, the research results are discussed in the context of the Lakeshore Capacity Study as a whole in the Integration report, in the section on the Water Quality Submodel.

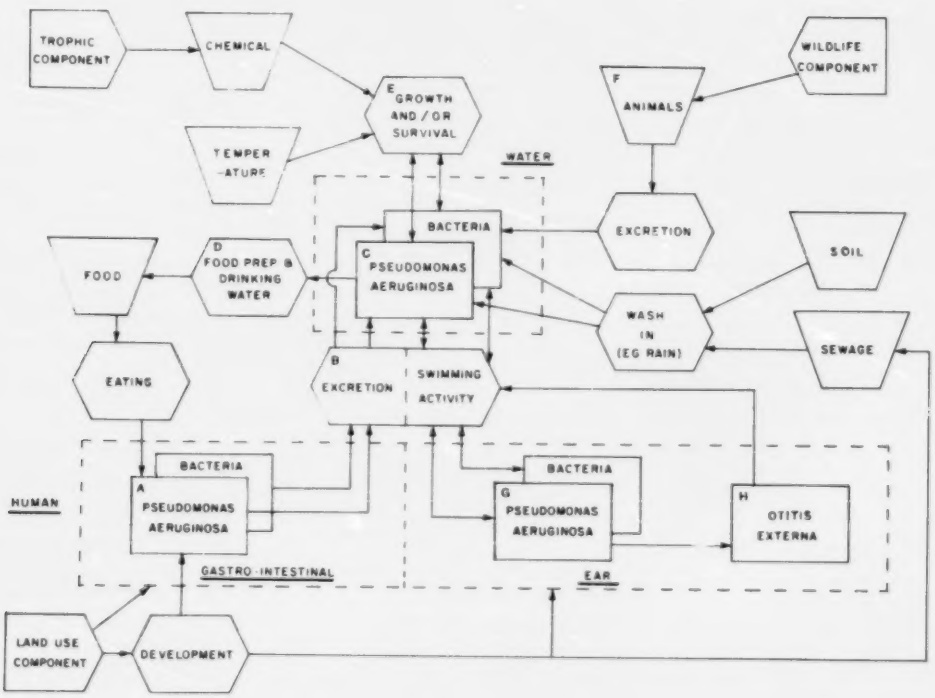

Figure 9. Flow diagram for *Pseudomonas aeruginosa* and its relationship to swimming activity and the ear infection *otitis externa*

7. FISHERIES COMPONENT

The construction and subsequent use of cottages and associated facilities on the lakeshore can affect the fisheries in several ways, including changing the trophic status of the lake; altering the spawning, nursery and feeding grounds of the fish; and increasing the fishing pressure. The goal of the Fisheries Component net productivity researchers was to develop a method of predicting the impact of lakeshore cottages on fisheries, as a result of fishing pressure.*

The production of sport fish and each intermediate link in the food chain depend ultimately on the supply of nutrients (Figure 10). Because phytoplankton require sufficient sunlight to support photosynthesis, the shape of the lake basin also affects trophic status. The fraction of the lake volume receiving sunlight is usually smaller for a deep lake than for a shallow one.

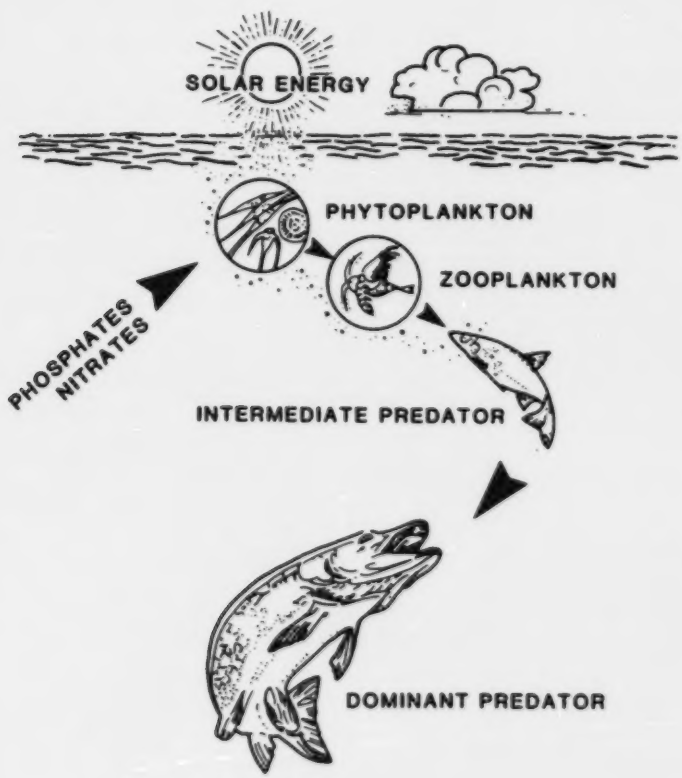

Figure 10. A typical aquatic food chain illustrating the connection between dissolved solids such as phosphates and nitrates, solar energy and, ultimately, the production of game fish (e.g.northern pike)

* This chapter is based on the report Lakeshore Capacity Study, Fisheries, Net Productivity: Index of Cottage Impact on Fisheries (McCombie, 1983).

7.1 EXISTING MODELS

A relationship between fish catch, water chemistry and geology was described by Ryder (1965). Based on a study of 23 lakes in Ontario, he found that the fish catch, or yield, was related to the ratio of total dissolved solids (an edaphic characteristic) and mean depth of the lake (a morphometric characteristic), which he called the morphoedaphic index (MEI). Total dissolved solids are a measure of the overall contribution of nutrient elements to the lakes from the watershed, while mean depth is an indicator of the fraction of the lake volume suitable for photosynthesis.

In the 1970's, Jenkins and Morais (1971) and Henderson and Welcomme (1974) found that fish catches were also strongly correlated with fishing pressure. Henderson and Welcomme combined the fish yield, morphoedaphic index and commercial fishing effort in a single model.

7.2 APPROACH TO EVALUATING THE IMPACT OF LAKESHORE COTTAGE DEVELOPMENT ON FISHERIES

Creel censuses were conducted on 46 lakes in the Muskoka-Haliburton area, during the summers of 1975-79 and the winters of 1976-79, to obtain information regarding anglers and their catch. The lakes were selected to give a representative sample of lake surface area, mean depth, total dissolved solids content, fish species and degree of cottage development on the lakeshore.

The creel census involved interviews with anglers on the lake. On each census day, the census-taker made one trip around the lake and interviewed all anglers on the route. Information was collected on the number of anglers in the party, number of hours fished prior to the interview, estimated total number of hours the party expected to fish that day. type of anglers (cottagers or non-cottagers), origin of anglers (home location), and the number of fish caught, released and sampled. When possible, fish length and weight were also recorded. From the summer of 1977 on, scale samples were collected to determine the age of the fish.

Anglers from cottages on the lake were separated from non-cottage anglers for analytical purposes, in order to estimate the fishing pressure exerted by each group, on each lake. For non-cottagers, the information on home location was analyzed to determine whether they came from distant points or communities near the lake.

As angling seasons for various species may differ with respect to opening and closing dates, which may also vary from year to year, an arbitrary number of days was assigned to each season. The summer fishing season was assumed to be May 1 to September 30 (153 days) and the winter fishing season January 1 to March 31 (91 days).

7.3 RESEARCH RESULTS

Analysis of the creel census data from the net productivity study lakes indicated that most fishing parties spent from two to four hours per day angling in summer, whereas in winter a considerable proportion spent up to six hours per day. The Fisheries Component biologists attributed the shorter fishing day in summer to the greater choice of aquatic recreational activities available in summer and to fishing parties including children, who have a short attention

span for angling. They suggested that the longer fishing day in winter might reflect difficulty in reaching the fishing site, relative comfort of the fishing hut and the amount of free time available to local residents in winter.

A consistent relationship was evident between fish catch during the summer and the morphoedaphic index. In addition, the summer catch of all fish species was related to summer angling effort.

The next step was to link angling effort to cottages. The number of anglers was calculated from the number of cottages on the lakeshore, by assuming an average number of anglers per cottage. Angling effort was then estimated by multiplying the number of anglers by the average number of hours per fishing trip, based on creel census data.

An indirect approach was used to estimate angling effort for non-cottagers. Assuming that a lake which was popular with cottagers was also likely to be popular with non-cottagers, the non-cottager angling effort was related to cottager angling effort. The correlation between cottager and non-cottager effort was found to be highly significant for the net productivity study lakes.

Estimates of winter angling effort were also derived indirectly, because many winter anglers could not be identified with points of origin on the lakeshore. Some came from nearby villages while others were from cities a considerable distance away. It was assumed that fisheries which attracted anglers in summer would also attract anglers in winter. The regression analysis showed a strong correlation between summer and winter angling on the net productivity lakes.

Winter angling differed from summer angling in terms of the people involved. Creel census data showed that, on average, cottagers accounted for 52% of the total summer angling effort but only 14% of total winter effort. Day-trippers and local residents formed the largest groups of anglers in winter on the net productivity lakes.

Some authors have reported that winter angling may be more effective than summer angling and may take a larger proportion of small, immature lake trout. On the net productivity lakes, this was not evident from creel census data, so an angler-hour of winter effort was considered to be equivalent to an angler-hour of summer effort.

7.4 NET PRODUCTIVITY MODEL

The morphoedaphic index combines water chemistry with lake morphometry and relates the trophic status of the lake, as measured by production of game and commercial fish, to the geology of the lake basin and watershed. The net productivity index incorporates this concept and adds angling effort as another predictor. The latter provides a link to cottage development, as angling effort is estimated from the number of anglers which, in turn, is derived from the number of cottages.

The net productivity index is designed to predict fish yield from the lake. This does not, in itself, indicate the number of cottages that can be built on the lakeshore without generating undue pressure on the fishery. However, when the predicted fish catch is compared with the maximum sustained yield, the effects on the fishery become evident.

The maximum sustained yield for the fish community is the maximum weight of two or more fish species which could be removed from the lake without altering

the kinds and sizes of fish caught. Similarly, the maximum sustained yield for a particular species, say lake trout, is the maximum weight of lake trout which could be removed from the lake year after year without significantly altering the ages and sizes of lake trout caught.

In the net productivity model, the weight of fish removed by anglers is predicted by a series of regression equations, derived from data obtained from anglers on 46 lakes in the Muskoka-Haliburton area plus data for ten lakes selected from the literature. The equations can predict:

(1) summer angling effort by cottagers,
(2) summer effort by anglers other than cottagers,
(3) total winter effort by all anglers, and
(4) total fish catch (yield) by all anglers.

In general, if the angling yield is greater than the maximum sustained yield, the fishery is considered to be overexploited. In contrast, if the fish catch is less than the MSY, the fish population can tolerate more fishing pressure.

While the community maximum sustained yield provides a good first approximation of potential fish production for a lake, exploitation of the fishery at this level is considered unwise. For one reason, fishing pressure may have a greater impact on some fish species than on others. For another, some year classes may be weaker than others. Accordingly, to provide a margin of safety, the Fisheries Component biologists recommend that fisheries be managed to take some fraction of the maximum sustained yield, termed the allowable yield.

In the net productivity model, the yield obtained from Ryder's morphoedaphic index model is taken as an estimate of the MSY for a fish community. However, in order to use the model for a particular fish species, such as lake trout, the MSY for that species must be estimated. This can be done by analyzing the catch statistics, by species, for fisheries which appear to be withstanding current fishing pressures. Recent work by the Ontario Ministry of Natural Resources has produced estimated MSY values for smallmouth bass, whitefish and northern pike, as well as revised MSY values for lake trout and walleye. The MSY value for lake trout, for example, is 0.25 MSY_c, reflecting the fact that lake trout comprised, on average, one-quarter of the total fish catch.

Mathematical formulations for the net productivity model appear in the Fisheries report, where the derivation of the model is described in detail. In addition, the net productivity model is discussed in the Integration report in the context of the Lakeshore Capacity Study as a whole.

8. WILDLIFE COMPONENT

A wildlife community has a network of interrelationships among all species. The organisms are linked together by their effects on one another and their responses to the environment they share (Figure 11).

Shorelines provide a unique set of biophysical environmental features which significantly affect wildlife species. For study purposes, the shoreline communities were defined by the Wildlife Component as those within 100m of the water. The objective was to determine the impact of lakeshore cottage development on wildlife.*

From the wildlife community, the wildlife ecologists selected the following species or groups of species for study: songbirds, common loons, hawks, small mammals, mink, deer, reptiles and amphibians. These were chosen because they represented major parts of the wildlife community, reflected a wide range of values people place on wildlife, and occurred in sufficient numbers to enable investigation.

* This chapter is based on the report Lakeshore Capacity Study, Wildlife (Euler, 1983).

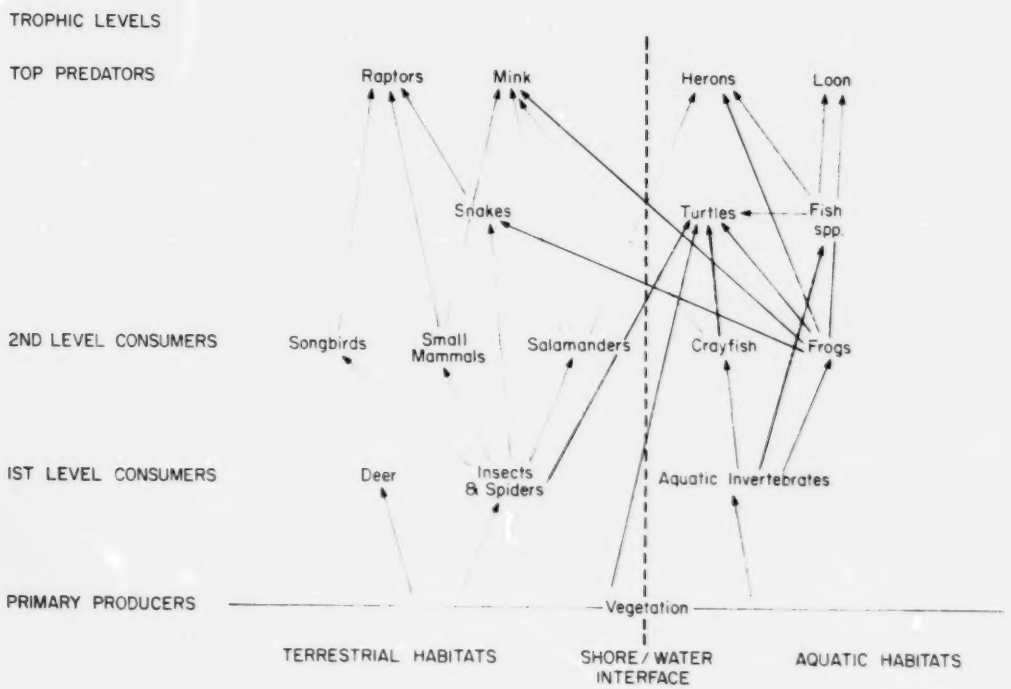

Figure 11. Diagrammatic representation of an ecological food web

Cottage development involves the construction of both cottages and associated structures such as roads, transmission lines, boathouses, beaches and docks. Usually cottagers clear portions of the shoreline for lawns and patios. In addition, they may remove vegetation in the littoral zone to facilitate boating and swimming. An underlying assumption was that the impact of cottage development on wildlife species was caused largely by changes in vegetation. The starting point, therefore, was vegetation measurement and analysis.

Several indices were developed by the wildlife researchers to provide a measure of the vegetation disturbance associated with cottage development (Table 6).

Table 6. Development indices used in the Lakeshore Capacity Study wildlife analysis

	Name	Definition	Application (Wildlife Technical Report Chapter)
ADI	Area Development Index	ADI = GDI + SDI + TDI	Mink (8) Small Mammals (9) Habitat Disturbance (2) Vegetation (1)
GDI	Ground Development Index	Proportion of total area disturbed in ground vegetation layer	Songbirds (7) Habitat Disturbance (2)
SDI	Shrub Development Index	Proportion of total area disturbed in shrub vegetation layer	Habitat Disturbance (2)
TDI	Tree Development Index	Proportion of total area disturbed in tree vegetation layer	Habitat Disturbance (2)
CLDI	Cottager Loading Development Index	CLDI = log(CxU/AxD)	Mink (8)
LDI 150	Loon Development Index 150	Number of cottages within 150m of nest	Loons (4)
LDI 250	Loon Development Index 250	Number of cottages within 250m of nest	Loons (4)

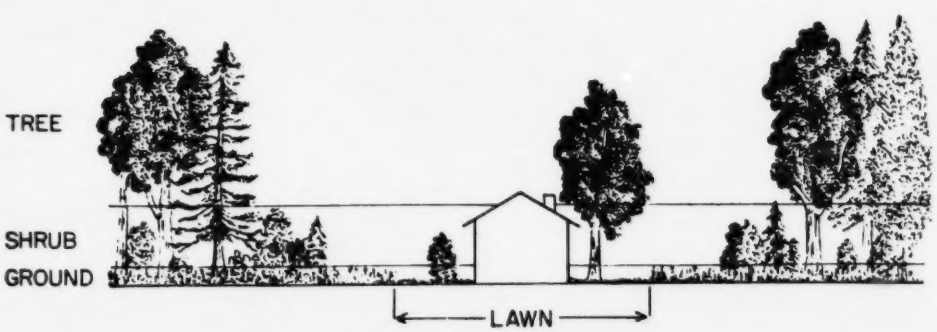

Figure 12. Schematic diagram of a cottage lot, illustrating differential disturbance in the ground, shrub and tree layers

The Area Development Index (ADI) was designed to quantify the disturbance in each of the three vegetation layers, i.e. the tree, shrub and ground layers (Figure 12). The Ground Development Index (GDI) measured the area disturbed in the ground layer. The ADI was used in the analysis of the impact on small mammals and mink; the GDI was used for the songbird research.

An analysis of cottage lots indicated that the area disturbed on a cottage lot was relatively uniform, regardless of lot size. A relationship between the ADI and lot size was identified, making it possible to predict the ADI from information on lot size. Moreover, as the response of many wildlife species to development was measured against the ADI, it was possible to calculate animal responses to cottage development from data on lot size.

To determine how the alterations in vegetation affected wildlife species, it was necessary to define the habitat of each species. Vegetation was sampled in the vicinity of wildlife or of physical signs of wildlife, such as deer tracks or mink dens. The habitat characteristics selected and the experimental design for the study of each species or group of species was based on knowledge of the natural history of the species being examined.

It was assumed that the impact on a particular species was related to the amount of its preferred habitat around the lake. The relationships derived from the research allowed predictions of impact to be made from readily available information on shoreline forest cover type (coniferous, deciduous or mixed wood) and cottage lot size.

The wildlife research indicated that lakeshore lots with cottages had less shrub cover and a lower ratio of coniferous trees. It was also evident that wildlife species differed in their ability to tolerate cottage development; some species could adapt to changes in their habitat while others were sensitive to minor alterations in vegetative composition.

8.1 VEGETATION (WILDLIFE HABITAT)

The vegetation on undisturbed shorelines was analyzed in terms of three types of habitat (coniferous, deciduous and mixed wood) and three layers of vegetation (tree, shrub and ground). Coniferous habitat was found to be typical of the lakeshore for most lakes in the Study Area, while deciduous and mixed habitat types more closely resembled backshore areas.

Data were also collected to provide detailed information about the changes in vegetation associated with development. The two major impacts identified were the replacement of natural lakeshore species by either domesticated or weed species and the overall loss of vegetation. Selected cutting of trees, for example, often resulted in the removal of conifers and the retention of white birch.

8.2 SONGBIRDS

Songbirds depend on the availability of suitable habitat; some species require specific features while others can adapt to a wide range of habitat characteristics. The red-eyed vireo, for example, needs relatively mature trees whereas the American robin can exploit conditions varying from lawns to less disturbed forest.

The reaction of individual species to cottage development was measured, as well as the response of the songbird community. Some species could not tolerate even low levels of development; others seemed virtually unaffected by cottages;

and some even benefited from disturbance. Analysis of the songbird community indicated that extensive cottage development changed its composition (Figures 13 and 14).

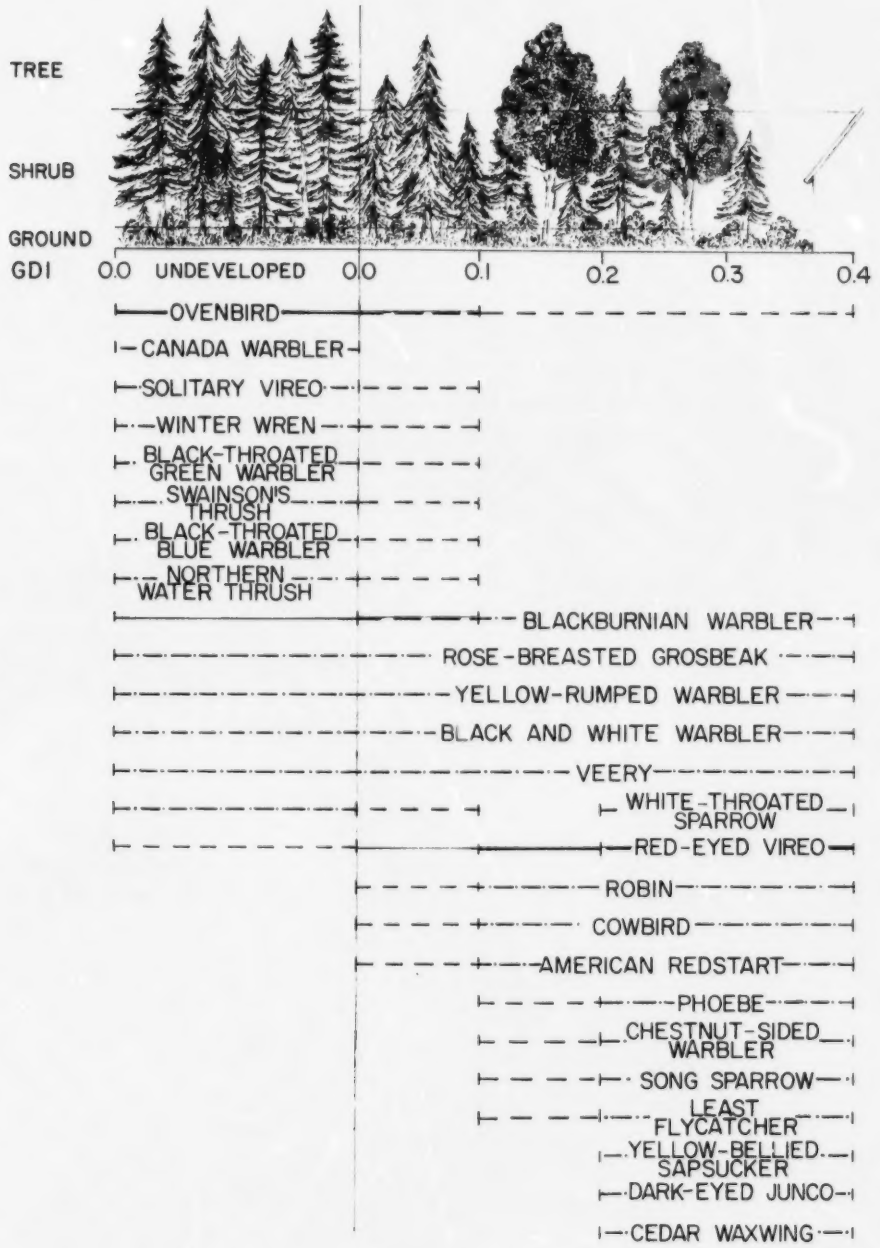

Figure 13. Songbirds in coniferous habitat at varying levels of development

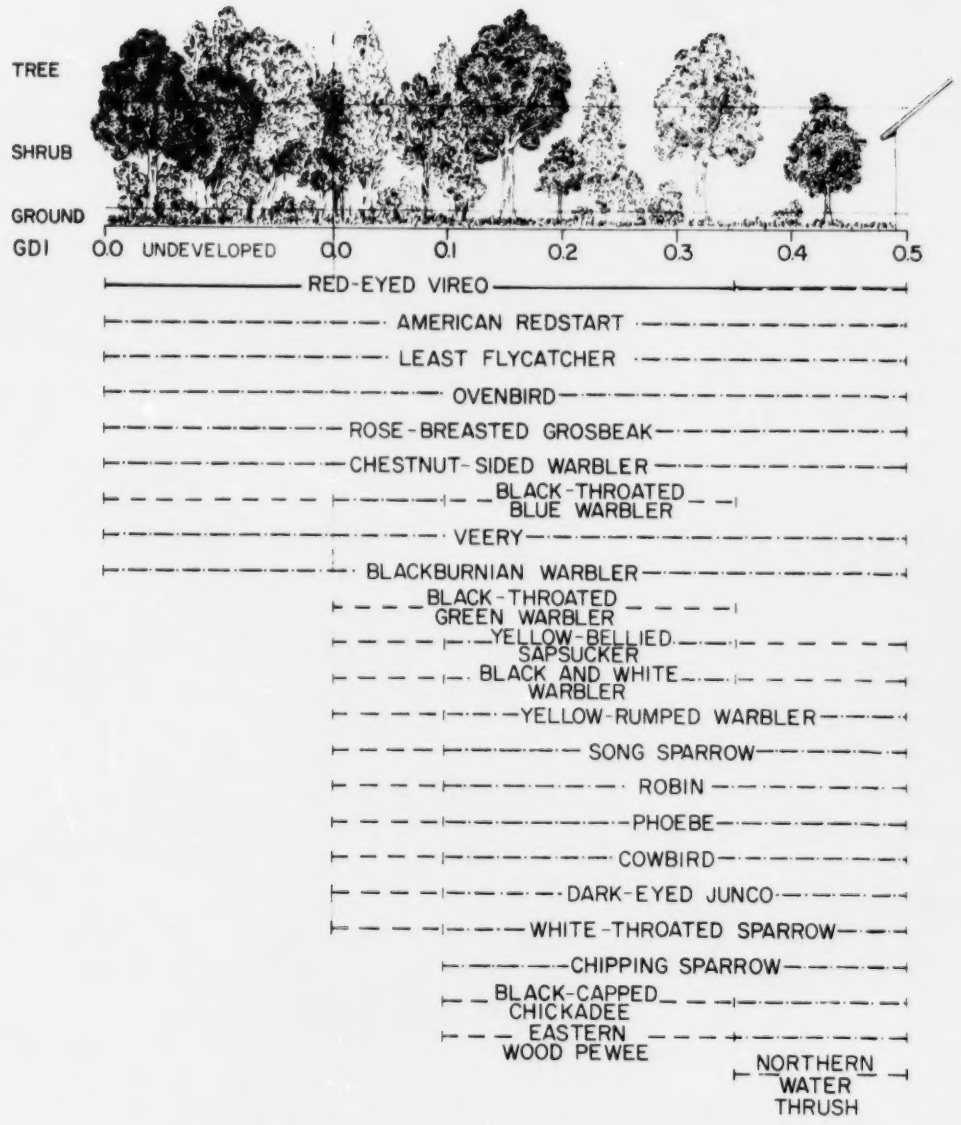

Figure 14. Songbirds in deciduous habitat at varying levels of development

8.3 COMMON LOONS

Nesting sites of the common loon were found primarily on small islands or bog hummocks. Characteristic features included gently sloping shoreline and abundant ground and shrub cover. There was a marked tendency for loons to utilize the same nesting site over a period of consecutive years.

Habitat characteristics were statistically similar for successful (with at least a single egg hatching) and unsuccessful nesting sites. It was assumed, therefore,

that non-habitat factors were relevant. As significantly fewer nests were found in the vicinity of cottages, the level of human activity was thought to be a factor in reduced nesting success.

Loons can live up to 20 years in the wild, so the effects of changing reproductive success cannot be detected in a short-term study. While loons are still commonly observed in the Muskoka-Haliburton area, it is not known whether the loon population is increasing or decreasing.

8.4 HAWKS

The two species of hawks found in high densities in the Study Area are the broad-winged hawk and the red-shouldered hawk. These avian predators have a large hunting range.

The broad-winged hawk needs younger deciduous stands which often occur after the construction of cottages and associated structures. For this reason, cottage development initially tends to improve, or at least maintain, the broad-winged hawk habitat. The greatest source of disturbance appeared to be human activity. This species establishes nests during the latter part of May, which coincides with an influx of cottagers around the Victoria Day long weekend. Such activity could cause nest disturbance or desertion, because defense of the nesting site is weakest during the period of territorial establishment.

Red-shouldered hawk habitat falls into two broad categories: upland deciduous areas and lowlands along streams and small rivers. This species requires a continuous forest of at least 10 ha. Cottage roads could fracture and isolate valuable habitat along lakes and streams.

8.5 SMALL MAMMALS

The small mammals studied included mice, shrews, voles, chipmunks and squirrels. These animals play an important role in shoreline wildlife communities, by converting plant and insect biomass into animal matter and providing a food source for higher level land predators, such as mink and raptors.

The response of small mammals to cottage development varied with the species and the coniferous composition of the habitat. Some species, such as the woodland jumping mouse and masked shrew, not only declined in number as cottages increased but were extirpated at higher levels of development. Other species, including the red squirrel and eastern chipmunk, were more tolerant of development.

8.6 MINK

Mink live along lakeshores and streams throughout most of Ontario. They require a relatively undisturbed habitat and an adequate food supply to reproduce successfully. Aquatic animals like crayfish and frogs as well as terrestrial animals like mice and shrews make up their diet. Mink are good indicators of environmental perturbation, as they are sensitive to changes in water quality, vegetative composition along the shoreline, and the abundance of their food supply.

Mink activity was greatest on undeveloped shorelines with coniferous and mixed vegetation; deciduous shorelines were used very little, regardless of the level of development. Mink activity decreased with even slight increases in the amount of cottage development (Figure 15). The wildlife scientists attributed this to a reduction in available food, hunting locations and denning sites.

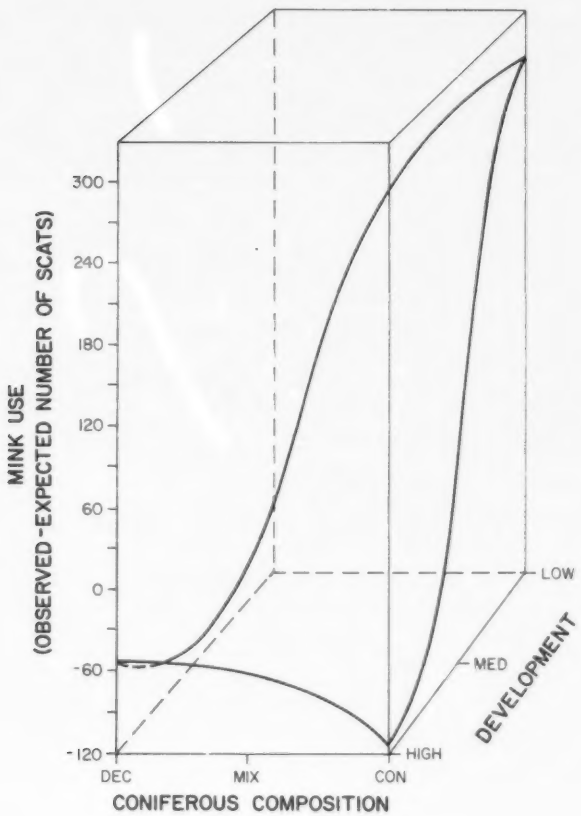

Figure 15. Mink response to development and habitat type

8.7 WHITE-TAILED DEER

Four types of deer habitat were studied, including travel lanes from one conifer stand to another, night bedding sites, day bedding sites, and feeding sites. These habitat types had significantly different characteristics. The night bedding areas and travel lanes had a dense, continuous, closed canopy of coniferous trees to provide protection from severe cold and wind; the day bedding sites had low overhead cover to permit the sun to penetrate; and the feeding sites had the greatest amount of food.

Shorelines with cottages had a lower percentage of coniferous trees and less shrub cover, due to cutting and pruning by cottagers. As tree removal interrupts the continuity of the coniferous fringe, it adversely affects the suitability of the habitat for deer.

8.8 REPTILES AND AMPHIBIANS

Reptiles and amphibians form an integral part of food chains, as predators of insects and their larvae and as prey for higher level consumers.

The most common species of turtle in Muskoka-Haliburton are the snapping turtle and eastern painted turtle. For optimum breeding success, turtles require sandy areas free of vegetation, with a clear path to the water. Turtles live up to 20 years, so it was not possible to determine their long-term response to cottage development. Nevertheless, it was clear that the increased road traffic and destruction of egg-laying sites associated with cottages had a negative effect.

Amphibians are most common in the moist habitat along streams and lakes. As most species require terrestrial and aquatic habitat, it was necessary to examine both the vegetation and water chemistry of their habitat. Densities of amphibians were measured throughout the spring and summer along streams, lakes and ponds. For all amphibians studied except bullfrogs and spotted salamanders, disturbance caused by cottage development was detrimental to habitat quality.

8.9 LAKELIFE

The results of the wildlife research were incorporated into a computerized information system known as LAKELIFE, which predicts the effects of cottage development on wildlife. A full description of LAKELIFE appears in the Lakeshore Capacity Study report on Wildlife.

The predictions are in the form of indices for each species or group of species. Some of these are calculated from estimates of certain vegetation parameters which have been shown to change with development; others depend on the Area Development Index (ADI). The calculations and assumptions used in LAKELIFE are described in the Wildlife report. In addition, the methods of predicting the impact of lakeshore cottage development on wildlife are discussed in the context of the Lakeshore Capacity Study as a whole in the Integration report, in the section on the Wildlife Submodel of the Ontario Lakeshore Capacity Simulation Model.

8.10 RECOMMENDATIONS

The recommendations of the Wildlife Component biologists are designed to protect the wildlife community as a whole. Along a stream, for example, the habitat left undisturbed could preserve amphibians and other small aquatic life as well as broad-winged hawk nesting sites, small mammal and songbird habitat, and other wildlife species in the community.

Where minimum habitat requirements are not met, the potential exists for serious losses to individual lakeshore wildlife communities. Clearings for cottage development alter habitat structure sufficiently that the small mammal and songbird species which require a closed canopy, small openings, and/or mature forest would disappear from the shoreline. The combined effect of the reduction in diversity and abundance of songbirds, small mammals, and amphibians would change the natural food web, thereby reducing the number of predators such as mink. Even though these predators could feed on prey species like chipmunks and robins, that increase in number with development, they would still be affected adversely by disruption of their denning and breeding sites.

The Wildlife Component biologists made specific recommendations with respect to the degree of acceptable change in wildlife communities as a result of cottage development. As decisions regarding acceptability involve subjective judgement and reflect attitudes and beliefs, the wildlife biologists may not always be in full agreement with planners or decision-makers. This does not detract from the value of the wildlife recommendations, as long as their underlying premises are clear.

Two major premises formed the basis for evaluating the acceptability of changes in the wildlife community:

i. Wildlife populations must be maintained in self-sustaining communities that are as similar as possible to undisturbed shoreline communities, on some portions of all lakes.
ii. There must be no extirpation of any species from the shoreline community of any lake.

The following specific recommendations of the Wildlife Component biologists are designed to benefit the wildlife community as a whole.

(1) A Lakeshore Habitat Monitoring System should be introduced in areas where lakeshore cottage development occurs. This system should:
   (a) identify all potentially significant impacts of cottage development on lakeshore wildlife and wildlife habitat for each lake;
   (b) build an inventory of lakeshore habitats; and,
   (c) act as a data base with which cottage development plans can be evaluated, using LAKELIFE to test different management strategies.

   The first stage of this system should involve the identification of sensitive areas on the lake shoreline and the collection of data required to execute the program for the LAKELIFE Simulation Model.

(2) All shoreline habitat for rare, threatened, or endangered species, both plant and animal, should be treated in accordance with current legislation and protected.

(3) Development should not be permitted if wetlands are to be filled or isolated from the lake. A wetland is any area covered by standing water until about July 1st each year.

(4) Any lakeshore identified as a winter deer concentration area should be protected, but the area reserved need not exceed 5% of the total shoreline length. Service lines and roads passing through these areas to cottages elsewhere on the lake should be at least 120m from the shoreline.

(5) To preserve at least one pair of nesting loons on each lake, two islands of at least 0.5 ha should be left undeveloped. On lakes without two islands of that size, two areas of at least 500m of shoreline and 100m inland should be reserved, each centred on a potential loon nesting site.

(6) To maintain hawk nesting sites along lakeshores, at least two actual or suitable nesting areas should be designated. No cottage development should be permitted within 150m.

(7) At least two potential turtle egg-laying sites should be left undeveloped on each lake. Each site should be at least 1 ha in area, with at least 100m of shore.

(8) To maintain amphibian populations, 50% of the segments (as defined in LAKELIFE) containing a stream entering or leaving a lake should remain undeveloped.

(9) The model LAKELIFE should be used to predict the impact on wildlife habitat of proposed cottage developments. It reduces the complex requirements of all these species to a series of simple values which can be easily interpreted. The minimum levels of values computed by LAKELIFE which will allow the premises to be met are the following:

- The small mammal Capture Index should not be below 25% of its original value for each of the seven indicator species.
- Mink activity should not be less than one-third of its value before development. The Cottager Loading Development Index, which reflects good mink habitat, should be below 1.0.
- For each of the 19 songbird species listed in LAKELIFE, 25% of the original nesting habitat should be preserved. In addition, the Coefficient of Community, a measure of the change in bird species, should remain the same on 25% of the lakeshore.

In addition, loon, hawk, turtle and amphibian habitat requirements are incorporated into LAKELIFE, based on the above recommendations.

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APPENDICES

A. LAKESHORE CAPACITY STUDY:
PEER REVIEW

B. LAKESHORE CAPACITY STUDY:
PUBLISHED REPORTS

C. LAKESHORE CAPACITY STUDY:
TECHNICAL PUBLICATIONS

APPENDIX A. PEER REVIEW

To ensure the soundness of the research undertaken by each of the components, the Steering Committee invoked a peer review. For each component, several reviewers were chosen who had practical experience and recognized qualifications in the appropriate field of investigation. Other criteria included specialized knowledge of statistical techniques and familiarity with the Study Area.

Some of the peers have dual roles as university professors and consultants and many are widely known among their professional colleagues, both nationally and internationally.

The names of the peer reviewers are listed, by component. Their affiliations are those at the time of the Lakeshore Capacity Study peer review.

LAND USE COMPONENT	**PEER REVIEW**
John R. Bousfield, M.C.I.P. John Bousfield Associates Consulting Town Planners Toronto, Ontario	1977
Thomas L. Burton, Ph.D., M.C.I.P. Professor and Chairman Department of Recreation Administration The University of Alberta Edmonton, Alberta	1983
R. S. Dorney, Ph.D., M.C.I.P. Consulting Ecologist Ecoplans Limited Waterloo, Ontario and Professor School of Planning Faculty of Environmental Studies University of Waterloo Waterloo, Ontario	1977 and 1982
Robert W. McCabe, Ph.D., M.C.I.P. Professor Emeritus University of Toronto Toronto, Ontario	1982
J. Ross Raymond, B.A.Sc., P. Eng., M.C.I.P. Planning Consultant Gravenhurst, Ontario	1977

J. C. Stansbury, B.L.A. Hough, Stansbury and Associates Limited Toronto, Ontario	1977
J. B. R. Whitney, Ph.D. EcoPact Assessments Toronto, Ontario and Professor Department of Geography University of Toronto Toronto, Ontario	1977 and 1982

FISHERIES COMPONENT

F. E. J. Fry, Ph.D. James F. MacLaren Limited North York, Ontario	1977 and 1981
R. H. Green, Ph.D. Associate Professor of Zoology Department of Zoology The University of Western Ontario London, Ontario	1981
Harold H. Harvey, Ph.D. Director Aquatic Environmental Affairs Branch Environment Canada Ottawa, Ontario and Professor Department of Zoology University of Toronto Toronto, Ontario	1977
John R. M. Kelso, Ph.D. Great Lakes Biolimnology Laboratory Environment Canada Sault Ste. Marie, Ontario	1977
Henry A. Regier, Ph.D. Institute of Environmental Studies University of Toronto Toronto, Ontario	1981
Carl J. Walters, Ph.D. Associate Professor Institute of Animal Resource Ecology The University of British Columbia Vancouver, B.C.	1981

MICROBIOLOGY COMPONENT

Victor J. Cabelli, Ph.D. Professor Department of Microbiology University of Rhode Island North Kingston, Rhode Island	1977 and 1981
Alfred P. Dufour, Ph.D. United States Environmental Protection Agency Wakefield, Rhode Island and Microbiology Laboratory University of Rhode Island North Kingston, Rhode Island	1981
B. J. Dutka, M.Sc. Head, Microbiology Laboratories Analytical Methods National Water Research Institute Canada Centre for Inland Waters Environment Canada Burlington, Ontario	1977 and 1981
Alfred W. Hoadley, Ph.D. Professor School of Civil Engineering and School of Biology Georgia Institute of Technology Atlanta, Georgia	1977
Patricia L. Seyfried, Ph.D. Associate Professor Department of Microbiology and Parasitology Faculty of Medicine University of Toronto Toronto, Ontario	1981
Alan D. Tennant, Ph.D. Manager, Laboratory Services Environmental Protection Services Ontario Region Environment Canada Ottawa, Ontario	1977

TROPHIC STATUS COMPONENT	
Joseph Shapiro, Ph.D. Professor Geology and Ecology Departments and Associate Director Limnological Research Center University of Minnesota Minneapolis, Minnesota	1977
F. H. Rigler, Ph.D. Chairman Department of Biology McGill University Montreal, Quebec	1977
K. Patalas, Ph.D. Research Scientist Eutrophication Section Fisheries Research Board of Canada Freshwater Institute Environment Canada Winnipeg, Manitoba	1977
WILDLIFE COMPONENT	
J. E. Bryant, M.A.* Director Ontario Region Canadian Wildlife Service Environment Canada Ottawa, Ontario	1981
F. F. Gilbert, Ph.D. Associate Professor College of Biological Science Department of Zoology University of Guelph Guelph, Ontario	1977 and 1980
John A. Livingston, Ph.D. Professor Faculty of Environmental Studies York University North York, Ontario	1977 and 1980
W. John Richardson, Ph.D.** Vice-President, Research LGL Limited Environmental Research Associates Toronto, Ontario	1980

*Review by staff of the Ontario Region, Canadian Wildlife Service.
**Review by staff of LGL, including W. John Richardson, Ph.D., R. A. Davis, Ph.D., and J. Green, M.Sc.

APPENDIX B. PUBLISHED REPORTS

Report	Ministry*
Lakeshore Capacity Study Committee Report**	Municipal Affairs and Housing
Lakeshore Capacity Study Integration	Municipal Affairs and Housing
Lakeshore Capacity Study Land Use	Municipal Affairs and Housing
Lakeshore Capacity Study Trophic Status	The Environment
Lakeshore Capacity Study Microbiology	The Environment
Lakeshore Capacity Study Fisheries	Natural Resources
Lakeshore Capacity Study Wildlife	Natural Resources

*The reports were prepared in the ministries noted. They were published by the Ministry of Municipal Affairs and Housing (1983) and the Ministry of Municipal Affairs (1986).
**A general summary of the Study results.

APPENDIX C. TECHNICAL PUBLICATIONS

TROPHIC STATUS COMPONENT
SCIENTIFIC PUBLICATIONS*

Dillon, P. J., D. S. Jeffries, W. Snyder, R. Reid, N. D. Yan, D. Evans, J. Moss and W. A. Scheider. 1978. *Acidic precipitation in south-central Ontario: recent observations.* **J. Fish. Res. Board Can.** 35:809-815.

Dillon, P. J., and R. A. Reid. 1981. *The input of biologically available phosphorus by precipitation to Precambrian lakes.* pp. 183-198. In **Atmospheric Input of Pollutants to Natural Waters,** S. Eisenreich, (ed.), Ann Arbor Science.

Dillon, P. J., and R. D. Evans. 1982. *Whole-lake lead burdens in sediments of lakes in southern Ontario, Canada.* **Hydrobiol.** 91:121-130.

Evans, H. E., P. J. Smith and P. J. Dillon. 1983. *Anthropogenic zinc and cadmium burdens in sediments of selected southern Ontario lakes.* **Can. J. Fish. Aquat. Sci.** 40:570-579.

Evans, R. D., and P. J. Dillon. 1982. *Historical changes in anthropogenic lead fallout in southern Ontario, Canada.* **Hydrobiol.** 91:131-137.

Jeffries, D. S., W. R. Snyder, W. A. Scheider and M. Kirby. 1978. *Small-scale variations in precipitation loading near Dorset, Ontario.* **Wat. Pollut. Res. Can.** 13:73-84.

Kurtz, J., and W. A. Scheider. 1981. *An analysis of acidic precipitation in southcentral Ontario using air parcel trajectories.* **Atm. Environ.** 15:1111-1116.

Scheider, W. A., W. R. Snyder and B. Clark. 1979. *Deposition of nutrients and ions by precipitation in south-central Ontario.* **Wat. Air Soil Pollut.** 12:171-185.

Scheider, W. A., D. S. Jeffries and P. J. Dillon. 1981. *Bulk deposition in the Sudbury and Muskoka Haliburton areas of Ontario during the shutdown of Inco Ltd., in Sudbury.* **Atm. Environ.** 15:945-956.

MOE DATA REPORT SERIES

Scheider, W. A., R. A. Reid, B. A. Locke and L. D. Scott. 1983. **Studies of lakes and watersheds in Muskoka-Haliburton, Ontario: Methodology (1976-1982).** Ont. Min. Envir. Data Report 83/1.

Jeffries, D. S., and W. R. Snyder. 1983. **Geology and geochemistry of the Muskoka-Haliburton Study Area.** Ont. Min. Envir. Data Report 83/2.

Nicolls, A., R. Reid and R. Girard. 1983. **Morphometry of the Muskoka-Haliburton Study Lakes.** Ont. Min. Envir. Data Report 83/3.

Reid, R. A., B. Locke and R. Girard. 1983. **Temperature profiles on the Muskoka-Haliburton Study Lakes (1976-1982).** Ont. Min. Envir. Data Report 83/4.

Reid, R. A., R. Girard and B. Locke. 1983. **Oxygen profiles on the Muskoka-Haliburton Study Lakes (1976-1982).** Ont. Min. Envir. Data Report 83/5.

Scheider, W. A., C. M. Cox and L. D. Scott, 1983. **Hydrological data for lakes and watersheds in the Muskoka-Haliburton Study Area (1976-1980).** Ont. Min. Envir. Data Report 83/6.

* The analysis of precipitation samples for the Lakeshore Capacity Study in the Muskoka-Haliburton area provided the first scientific evidence of the extent of acidic precipitation in Ontario. These publications are based on Lakeshore Capacity Study data.

Smith, P. J. 1983. **Sediment chemistry of lakes in the Muskoka-Haliburton Study Area.** Ont. Min. Envir. Data Report 83/7.

Nakamoto, L., L. Heintsch and K. Nicholls. 1983. **Phytoplankton of lakes in the Muskoka-Haliburton area.** Ont. Min. Envir. Data Report 83/8.

Hitchen, G. G., and N. D. Yan. **Crustacean zooplankton communities of the Muskoka-Haliburton Study Lakes: Methods and 1976-79 data.** Ont. Min. Envir. Data Report 83/9.

Girard, R., B. Locke and R. A. Reid. **Depth and volume of strata in the Muskoka-Haliburton Study Lakes (1976-1982).** Ont. Min. Envir. Data Report 83/10.

Dillon, P. J., and W. A. Scheider. **Total phosphorus and major ion mass balances for lakes in the Muskoka-Haliburton Study Area (1976-1980).** Ont. Min. Envir. Data Report

WILDLIFE TECHNICAL REPORT

This report includes the following research papers:

1. Clark, T., and D. Euler. 1981. *Vegetation disturbance caused by cottage development in central Ontario.*
2. Racey, G., and D. Euler. 1981. *An index of habitat disturbance for lakeshore cottage development.*
3. Clark, K., D. Euler and E. Armstrong. 1981. *Habitat associations of breeding birds in cottaged and uncottaged areas of central Ontario.*
4. Heimberger, M., D. Euler and J. Barr. 1981. *The impact of cottage development on common loon reproductive success in central Ontario.*
5. Armstrong, E., D. Euler and K. Clark. 1981. *Habitat selection within four passerine families in central Ontario.*
6. Armstrong, E., and D. Euler. 1981. *Reproductive ecology and habitat usage of woodland buteos in central Ontario.*
7. Clark, K., D. Euler and E. Armstrong. 1981. *Predicting avian community responses to lakeshore cottage development.*
8. Racey, G., and D. Euler. 1981. *Changes in mink habitat and food selection as influenced by cottage development in central Ontario.*
9. Racey, G., and D. Euler. 1981. *Small mammal and habitat response to shoreline cottage development in central Ontario.*
10. Armstrong, E., G. Racey and D. Euler. 1981. *Deer habitat quality and influence of cottage development in central Ontario.*
11. Clark, K., and D. Euler. 1981. *Reptile and amphibian habitat and human activity in central Ontario.*
12. Clark, K. and D. Euler. 1981. *The importance of pH and habitat disturbance in amphibian distribution in central Ontario.*